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THE PALEOECOLOGY OF A RAISED BOG AND
ASSOCIATED DELTAIC SEDIMENTS
OF THE FRASER RIVER DELTA

by

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B.Sc., McMaster University, 1973

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF

THE REQUIREMENTS FOR THE DEGREE OF

DOCTOR OF PHILOSOPHY

in

THE FACULTY OF GRADUATE STUDIES

DEPARTMENT OF BOTANY

We accept this thesis as conforming
to the required standard

THE UNIVERSITY OF BRITISH COLUMBIA

February, 1977

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ABSTRACT

In this study, three cores obtained from Burns Bog just south of the Fraser River in Delta, British Columbia, were analyzed palynologically. The paleoecology of the bog was reconstructed from the results of these analyses, together with data from vegetation studies of the bog, pollen rain and surface pollen spectrum investigations of selected wetland environments, as well as pollen tetrad and pollen productivity studies of bog ericads.

The vegetation of Burns Bog was sampled by estimating species cover in selectively placed 100 m² quadrats. These field data were used in combination with an air photographic mosaic to map the eight vegetation types of the area. The palynomorph "fingerprints" of selected wetland environments, determined from pollen rain and surface pollen spectrum studies, were used to recognize analogous phases recorded in cores. Tetrad diameter and pollen productivity data for bog ericads assisted in recognizing ecologically significant ericad species that distinguished wet and dry raised bog phases.

The study shows that Burns Bog has developed on Fraser River deltaic deposits which appeared above sea level just after 5,000 years BP. The seemingly synchronous emergence of the three core sites and a locality in adjacent Boundary Bay indicate a possible relative sea level decrease at this time. The silty emergent sediments are characterized by high percentages of Pinus and Picea pollen deposited by river water, and Cyperaceae pollen from local Scirpus and Carex stands. Following this emergence, sedges colonized the area, forming a sedge peat containing abundant Cyperaceae pollen. At the western end of the bog, a salt marsh developed

(4,125 \pm 110 BP) in response to a marine advance. This was possibly caused by a shut-off of fresh-brackish water from the Fraser River when the delta reached Point Roberts. In the eastern section of the bog, at the foot of Panorama Ridge, the sedge phase was only transient. A Myrica-Spiraea-Lysichitum swamp developed, remaining until very recently. After the sedge phase in the central part of the bog, Myrica and Spiraea thickets appeared; these were subsequently replaced by Sphagnum bog at 2,925 \pm 85 years BP. In the western end of the bog, sedges were replaced by heaths, predominantly Ledum. At the foot of Panorama Ridge, Sphagnum arrived very recently. Pines seem to have invaded all sites at the 2.00 m level.

The AP pollen spectrum shows that the regional upland vegetation remained unchanged throughout the history of Burns Bog until settlers cleared the forests. On the delta, however, fluctuations in alder pollen were probably associated with alder colonization of levees and swamps near the channels.

Fire has played an important role in bog ecology. Natural Sphagnum accumulation processes are modified because fire destroys the vegetation of slightly higher, dry sites. Unburned wet depressions then become centers of peat accumulation. These sites eventually rise above the surrounding burned areas, which are converted to depressions.

A model for raised bog development is proposed for the Fraser Lowland. The prograding delta-front is colonized by emergent aquatics growing on silts. This phase is followed by the advent of a sedge swamp perhaps containing some wetland grasses. Eventually, shrubs such as Myrica and Spiraea begin to appear, accompanied in the later stages by Ledum groenlandicum. Increased acidity of the substrate due to peat accumulation promotes

Sphagnum, which eventually takes over and results in the establishment of raised bog conditions.

This study, the first detailed outline of raised bog development in western North America, provides a framework for further investigations of bogs in the area.

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ACKNOWLEDGEMENTS

I am indented to many individuals who assisted with the technical aspects of this work and gave of their time for encouragement and discussion.

Financial support for the project was provided by the National Research Council of Canada through grants to Dr. G. E. Rouse and three scholarships to me.

Allen Banner assisted in the field and in the laboratory. Joan Miller also helped with laboratory preparations and drew some of the figures. Wayne G. Biggs, currently with Entech Environmental Consultants Limited, was a welcome co-worker in the study of Burns Bog vegetation. Thanks are expressed to Western Peat Moss Limited for allowing access to the parts of the bog under their control.

I would like to thank the many graduate students of the Botany Department of the University of British Columbia who tolerated the ravings of the "bog man" and provided welcome company in the field. I wish also to thank Leslie Borleske who typed the final draft of the thesis.

Special thanks go to the members of my thesis committee: Drs. R. L. Taylor, F. R. Ganders (Botany Department, University of British Columbia), W. H. Mathews (Geology Department, University of British Columbia), and R. W. Mathewes (Biology Department, Simon Fraser University). Dr. W. B. Schofield, also a committee member, deserves particular thanks for identifying the numerous bryophytes brought in from the bog.

Finally, I am immeasurably grateful to my supervisor, Dr. G. E. Rouse, whose patient discussion, encouragement and inspiration made my years as a graduate student a most exciting experience.

THE PALEOECOLOGY OF A RAISED BOG AND ASSOCIATED DELTAIC SEDIMENTS OF THE
FRASER RIVER DELTA, BRITISH COLUMBIA

CHAPTER 1: INTRODUCTION

The coastal zone of western North America contains many raised (ombrogenous) bogs. The paleoecology of these bogs, in contrast to European raised bogs (Moore and Bellamy, 1973; Godwin, 1975), has been studied only superficially. Among the first investigators in western North America was Anrep (1928), who evaluated peat reserves in southwestern British Columbia. Later Rigg and Richardson (1938) investigated bog ecology and peat stratigraphy in some raised bogs on the west coast. Hansen (1947) and Heusser (1960) carried out palynological investigations of bogs for the purposes of reconstructing regional forest history and climatic changes. Until now, however, there has been no concerted effort which combines both current vegetation studies and palynologic and stratigraphic approaches to elucidate the development of these bogs.

The main objective of this thesis is to provide the first detailed outline of the paleoecology of one of these raised bogs, Burns Bog, from the Fraser River Delta of southwestern British Columbia (Fig. 1). The main thrust of the present study is to apply palynologic and other paleoecologic techniques to reconstructing local vegetation history, rather than interpreting post-glacial, regional forest succession and climatic changes. The latter have already been considered for the area by Mathewes (1973) and Mathewes and Rouse (1975), from studies of lake sediments. In addition, this study intends to give fairly precise reconstruction of lower mainland

peatland and deltaic environments. These are based on microfossil assemblages preserved in three cores from the bog (Ch. 5-7), as well as on data obtained from investigation of pollen-vegetation relationships. The latter are based on studies of pollen-rain and surface samples of what are considered to be modern analogous communities (Ch. 4) together with analyses of plant assemblages within the Burns Bog area (Ch. 2).

The present investigation was initiated in Burns Bog (Delta Bog of Anrep (1928), Great Delta Bog of Osvald (1933) and Rigg and Richardson (1938)) for a number of reasons. Except for one preliminary investigation by Hansen (1940) on adjacent Lulu Island, little had been reported on the ecological successions within bogs of the Fraser River Delta. Although partly disturbed, this bog contains enough areas of relatively natural peatland to serve as a useful study area. This provided initially wide scope for analysis of vegetation-sediment relations within a region of complex deposition, water conditions, and diverse plant assemblages. Finally, factors such as human population growth, urban development, and peat exploitation have been increasingly interfering with the bog ecosystem and resulting in the destruction of large sections of the bog; thus information from certain areas had to be obtained before sites were permanently lost.

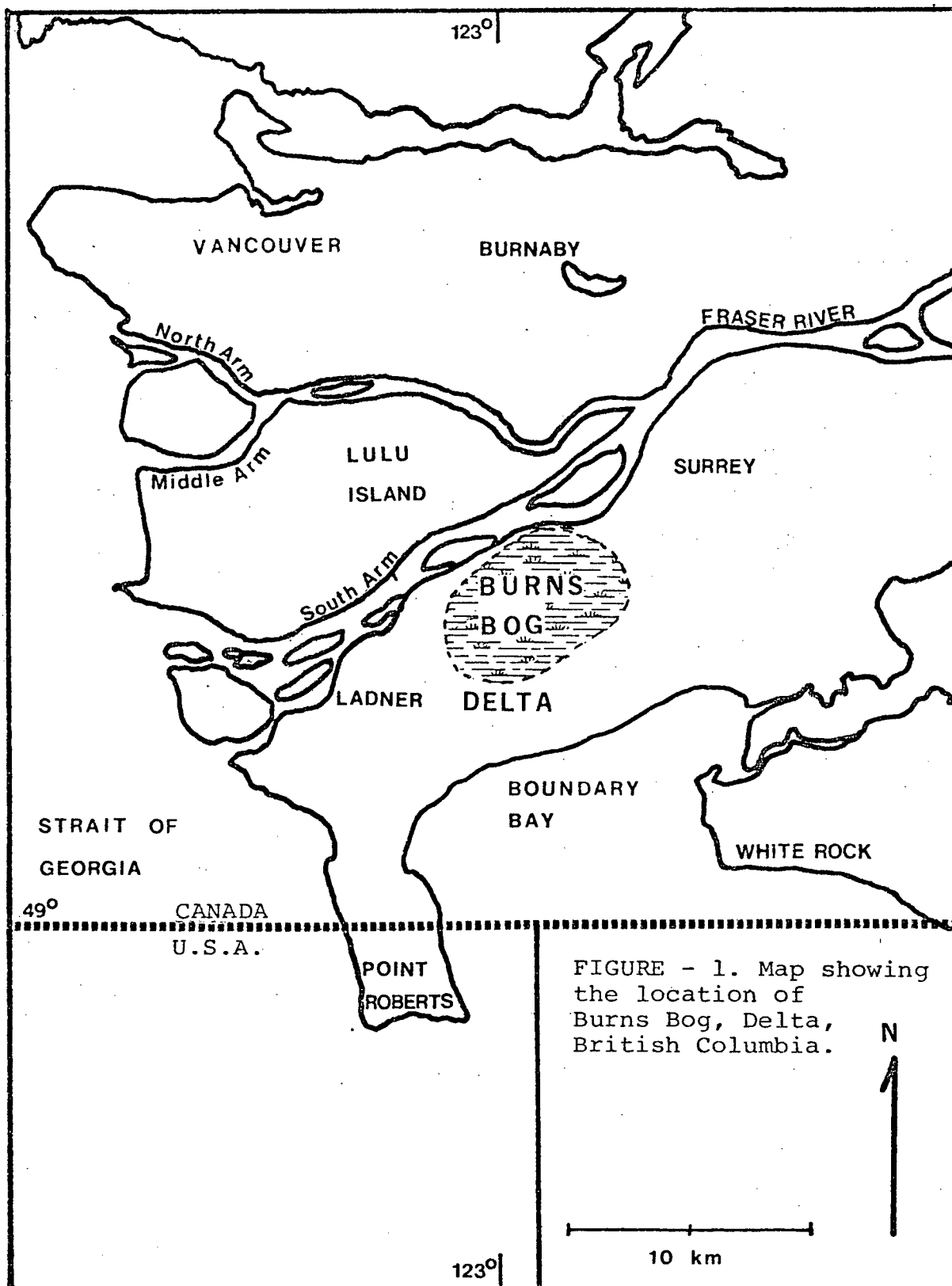
Investigation of Burns Bog paleoecology could be expected to shed light on a number of other basic problems. Included are those problems related to delta formation such as sedimentation, rate of development, age, channel changes, and sea level changes, as well as those related to bog development such as the sequence, duration and nature of plant communities

involved in raised bog formation, the nature of transitions, and the role of fire. Increased insight into these problems would be useful in predicting the natural development of current vegetation in the Fraser River Delta and foreseeing the effect of disturbance such as fire and drainage on the bog ecosystem. It would also provide a historical, environmental framework for interpretation of archaeological sites in the vicinity.

The Study Area

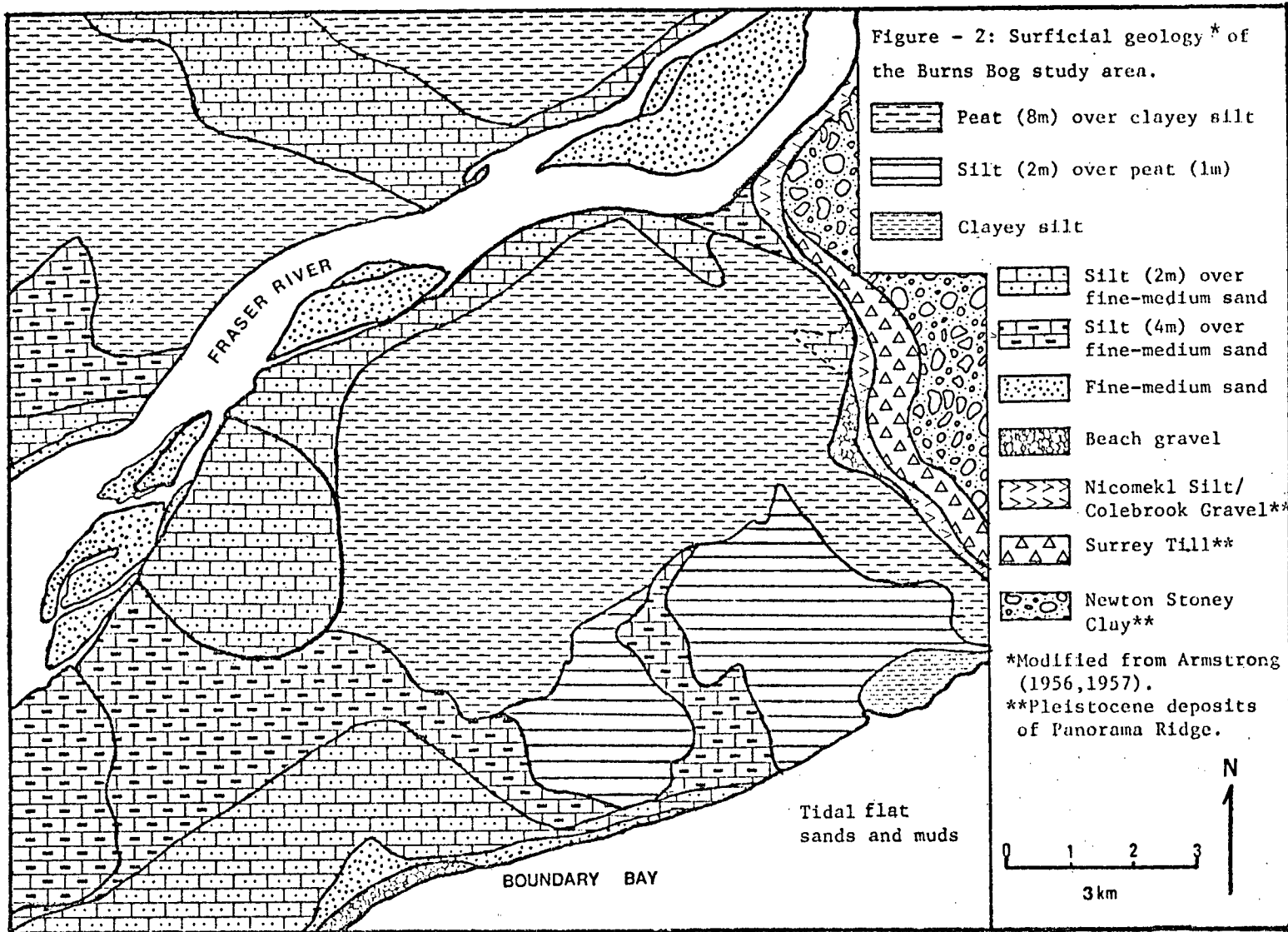
Physiography and Geology:

Burns Bog (latitude $49^{\circ}08'N$ and longitude $123^{\circ}00'W$) occupies approximately 4,000 hectares of the southern half of the Fraser River Delta in the Corporation of Delta (Fig. 1). Burns Bog and the Corporation of Delta lie within the Fraser Lowland subdivision of the Coastal Trough Physiographic Region (Luttmerding and Sprout, 1969). The western end of the Fraser Lowland containing Burns Bog and the Fraser River Delta occupy the northeastern corner of Whatcom Basin, a large subsiding trough that has been receiving sediments at least since the Upper Cretaceous (Rouse et al., 1975). Since then the surrounding area has been subjected to considerable tectonic and mountain building activity with the uplift of the Coast Mountains in the late Tertiary (Roddick, 1965). In the late Pleistocene, the Fraser Lowland was covered by some 1,500 m of ice during the maximum of the Vashon glaciation (Mathews et al., 1970). Deglaciation of the area began about 13,000 years ago (Mathews et al., 1970), with the Burns Bog region ice-free by about 12,600 BP (White Rock, B. C. $12,625 \pm 450$, IGSC6 (Walton et al., 1961), Point Roberts, B. C. $12,600 \pm 170$, IGSC248 (Trautman and Walton, 1962)). After ice retreat and during subsequent sea level readjustments from 10,000–9,000 BP (Blunden, 1975), the Fraser River began dumping sediments into the



area occupied by the present flood-plain. Around 10,000 BP the Fraser River penetrated through the Port Mann gap to the Strait of Georgia (Blunden, 1975). Subsequently the active Fraser River delta-front advanced at a rate of 9 m per year (Mathews and Shepard, 1962) and deltaic sediments built up to the point where the Island of Point Roberts was joined to the mainland (Blunden, 1975).

The surficial geology of the Burns Bog area (Fig. 2) has been mapped by Armstrong (1956, 1957). The east side of the bog is bordered by Panorama Ridge, part of the Surrey Upland, reaching elevations of 80 m. It consists of glacially derived outwash sands and gravels (Armstrong, 1957). Extensive well-sorted pebble beaches appear to have formed along the bottom portion of the westward slope of Panorama Ridge (Luttmerding and Sprout, 1969). On the south side of the bog, there are silty clays and sand, in places covered by shallow layers of peat (Luttmerding and Sprout, 1969). The salt marshes and tidal flats of Boundary Bay lie directly to the south of these deposits (Kellerhals and Murray, 1969). Salt marsh peats exposed by erosion in Boundary Bay were radiocarbon dated at $4,350 \pm 100$ years BP (Kellerhals and Murray, 1969). To the west of the bog up to 4 m of silty deltaic sediments, of marine and non-marine origin, overlie fine to medium sands. These silty deposits exhibit a gently undulating topography (Armstrong, 1956). An abandoned slough, Crescent Slough, defines the western edge of Burns Bog (Luttmerding and Sprout, 1969). North of the bog, the South Arm of the Fraser River is flanked by both natural and artificial levees. Between the river and the bog, shallow silts blanket fine to medium sand (Armstrong, 1956). Blunden (1975) has suggested that this channel of the Fraser River is of recent origin and became established when the river broke through the



large Greater Lulu Island-Delta (Burns Bog) peat bog sometime after 2,500 years BP.

Soils:

Most of the delta south of the South Arm of the Fraser River contains soils of the gleysolic and organic orders (Luttmerding and Sprout, 1969). The poorly drained mineral deposits have developed in a complex pattern dominated for the most part by saline orthic and saline rego gleysols or humic eluviated gleysols. In the area immediately around and including the bog, the organic soils range from sphagno-fibrisols to typic humisols.

Climate:

The climate of the area can best be described as a modified maritime type, or a Csb Koeppen Mediterranean type (Hoos and Packman, 1974). Winters are usually mild and rainy with peak rainfall in December, whereas summers are usually warm and dry with July being the driest month.

The nearest climatological station to Burns Bog is located at Ladner, 1 km south of the study area. This station records long term normals of precipitation, intensity of rainfall and temperature. The average annual precipitation at Ladner is 958 mm including an average annual snowfall of 37 cm. The annual average temperature is 9.2°C ; the July mean 16.7°C and the January mean 2.2°C (British Columbia Department of Agriculture, 1971). The average number of frost-free days is 183 (Luttmerding and Sprout, 1969). The prevailing winds blow from the southeast at an average velocity of 12.9-16.4 km/hr (8-10 mph). Strong winds are not common, and are usually associated with the passage of active weather disturbances blowing from the southeast or northwest. The relative humidity remains high throughout the

year, rarely dropping below 60%, with readings of 80-90% common. The meteorological station at Vancouver International Airport approximately 15 km northwest of the study area, records an average of 1900 hours of bright sun per year (Hoos and Packman, 1974).

The climatic conditions of Burns Bog are believed to be similar to those recorded at the Ladner station. Rainfall is probably slightly higher as a result of the increased orographic effect of the coastal mountains (Hoos and Packman, 1974).

Hydrology:

Topographic maps for the area (Department of Energy, Mines and Resources, 1970) indicate that Burns Bog is a dome-shaped mass of peat. The central cupola of the bog reaches about 5-6 m above mean sea level (a.s.l.), whereas the perimeter is about 1-2 m a.s.l. At the eastern end, peats onlap onto Panorama Ridge at about 5-6 m a.s.l.

The original drainage pattern of the bog is unknown. The trenching of drainage ditches and extensive conversion of peripheral areas to agricultural use early in the 20th century (Anrep, 1928) have obliterated many of the peripheral features that might have revealed this pattern. Current drainage patterns are governed by artificial ditches and pump-stations associated with the diking program of the southern Fraser River Delta. Generally, most of the northern portion of the bog drains northward to the Fraser River; the northwestern corner drains westward into Crescent Slough which empties into the Fraser River. In the southern part, flow is into the ditches that empty into Boundary Bay (Biggs, 1976). Along the north-eastern boundary, at the foot of Panorama Ridge, a sluggish stream previously carried water northward into the Fraser River. This stream has now been

replaced by a ditch that follows a recently installed (1974) trunk sewer, built more or less along the old stream course. During spring, when rains saturate the bog, water, presumably draining from the bog, often accumulates and moves slowly in Spiraea thickets around the bog periphery. Flow is commonly concentrated along cleared areas under B. C. Hydro power transmission lines. In a way, these seem to function as a lag.

Water levels in the bog can vary considerably. In the cupola, the water table fluctuates no more than .2 to .5 m between the wet winters and the dry summers. In peripheral areas where little Sphagnum grows, the water table (based on observations in shallow ditches) drops by at least a meter during the late summer dry spell.

Regional Vegetation:

The Fraser River Delta, on which Burns Bog is situated, lies within the Wetter Subzone of the Coastal Douglas-Fir Biogeoclimatic Zone of British Columbia (Krajina, 1969). Panorama Ridge and other upland areas around the bog are covered by vegetation more or less typical of this zone. Pseudo-tsuga menziesii is the dominant tree in mesic habitats, whereas Tsuga heterophylla predominates in sub-hygic sites (Krajina, 1969). Other important tree species of this zone include:

Thuja plicata

Abies grandis

Picea sitchensis

Pinus monticola (not present near Burns Bog)

Arbutus menziesii (not present near Burns Bog)

Prunus emarginata

Populus balsamifera subsp. trichocarpa

Acer macrophyllum

Acer circinatum.

Alnus rubra grows in disturbed areas; as a result of man's disruptive activity it is now a major component of upland vegetation.

The edaphic conditions of the immediate delta are not suitable for the development of douglas-fir forest. Currently, much of this area is covered by peat bog vegetation, farmland, and river or estuarine marshes and swamps. A narrow band of salt marsh vegetation borders Boundary Bay to the south of Burns Bog. The vegetation of Burns Bog itself is treated in Chapter 2.

Previous Studies:

The first investigation of Burns Bog deposits seems to be that of Anrep (1928), who produced an inventory of the economically valuable peat deposits of the lower mainland of British Columbia. He established a series of transects through the bog, and drilled holes to determine the depth of Sphagnum or humic Sphagnum peat. He found that Sphagnum peat was deepest (3.3 m) in the center of the bog (approximately at the present site of the Ladner plant of the Western Peat Moss Ltd.) and that it gradually decreased in depth in all directions from this point. Significantly, Anrep indicated a large "Area under cultivation or burnt over" surrounding the bog. This zone extended well beyond the present bog limits, particularly to the south. He also recognized that he was probably investigating a raised bog because: "the peat moss layer is above sea level and can be drained to the Fraser River".

Oswald (1933) noted the plant associations of Burns Bog, and indicated the similarity to those in Lulu Island Bog. He noted that the margins had been reclaimed in the southern part. Oswald did not comment on peat

stratigraphy.

The last published, early examination of Burns Bog peat deposits was carried out by Rigg and Richardson (1938). Using a Hiller borer, they ran a single transect from north to south and plotted a profile of the bog. Significantly, these workers plotted the surface of the bog as if it were flat rather than domed. The resultant vertical section distorted stratigraphic boundaries downward in the central part of the bog so that it appears that it formed in a shallow depression. It is possible that Rigg and Richardson (1938) knew that they were in a raised bog but had no way of correcting for elevational differences because the bog had not been surveyed.

Most recently, in a synthesis of data from both published and unpublished sources, Biggs (1976) (noting problems in peat classification) produced a peat isopach model for Burns Bog. When compared with surface topography, the depths indicate that the dome shape of the bog is due to Sphagnum peats, whereas the contact between these, and deposits below, is horizontal.

CHAPTER 2: THE VEGETATION OF BURNS BOG AND OBSERVATIONS ON PLANT ECOLOGY

Introduction

For the purposes of this paleoecologic study, knowledge of the vegetation of Burns Bog and the factors controlling plant distribution are considered to be critical to the understanding of fossil deposits. An understanding of the ecology of plant species and composition and dynamics of plant communities associated with bog development makes possible much more precise paleoenvironmental reconstructions. This chapter outlines the vegetation of present-day Burns Bog, discusses the vegetational structure before its alteration by major disturbance by immigrants and contains some observations and interpretations of the role of fire and Sphagnum growth on bog vegetation.

The Vegetation Types of Burns Bog

Several researchers have studied the plant assemblages of Burns Bog (Osvald, 1933; Rigg and Richardson, 1938; Beamish, Krajina and Bednar, 1968). To date, however, no detailed account of the vegetation has been published. As a result it was decided to map the vegetation and determine the quantitative, floristic composition of the major plant communities. The information presented here is a condensation of a study carried out in collaboration with W. G. Biggs, Plant Science Department, University of British Columbia (Hebda and Biggs, in preparation).

Methods

The vegetation of Burns Bog was investigated systematically during the

summer of 1975 as follows:

A preliminary base map, showing the generalized vegetation units, was prepared from a controlled air photographic mosaic. The mosaic (1" = 800') was created by Pacific Surveys Corporation for Western Peat Moss Ltd. from aerial photography BC5588, flown on July 12, 1974.

Field investigations of the area were initiated in June, 1975. A total of 6,000 m² of the bog was sampled quantitatively by placing sixty quadrats, 10 m x 10 m, at selected sites. Single quadrats or transect lines containing a number of quadrats, were located so that the more extensive vegetation types were well sampled whereas less important types were examined less intensively. Transect lines were run from the eastern, southern, western and northern peripheries toward the center of the bog. Examination of air photographs indicated that this transect line placement would ensure as thorough a sampling as possible of the major vegetation units in the limited time available. Quadrats were usually spaced at 100 m intervals along transects. However, where the nature of the vegetation changed rapidly, a 50 m spacing was used. Within each quadrat, cover estimates were made for tree and shrub species (Mueller-Dombois and Ellenberg, 1974). Shrub, herb, bryophyte and lichen cover was estimated in five plots, 1 m x 1 m, arranged inside the large quadrats as shown in Fig. 3. Additional vegetation information was collected in many areas where it was considered desirable to verify composition for the map. Voucher specimens of most species were collected for deposit in the Herbarium of the University of British Columbia. Species names and authorities used in the following description follow Taylor and MacBryde (1977) for vascular plants, Crum, Steere and Anderson (1973) for mosses, and Hale and Culberson (1970) for lichens.

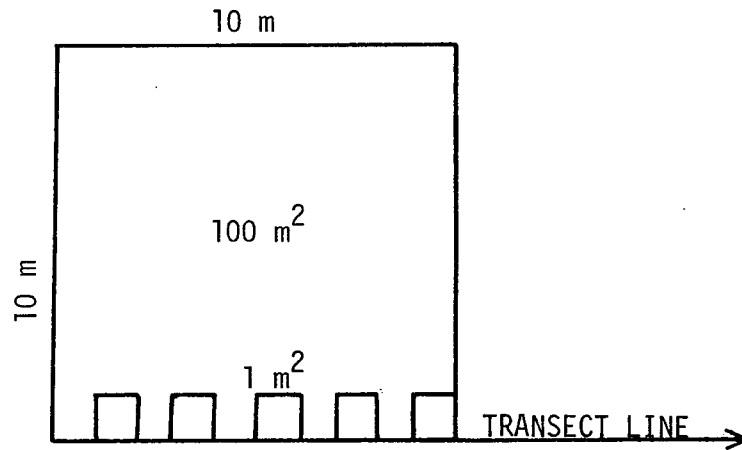


Figure 3. Arrangement of 100 m² and 1 m² Quadrats
Used for Vegetation Analysis in Burns Bog.

Information obtained from the quadrats was tabulated, with the quadrats subjectively grouped according to species composition and cover. Revisions of the original base map were made following analysis of quadrat data and examination of air photographs (1" = 500') of the area made available by the Land Assessment Department, Ladner, B. C. Vegetation types were delineated as being more or less homogenous assemblages of plants, recognizable and mappable on the air photographic mosaic (1" = 800').

Results

Eight vegetation types were recognizable in Burns Bog, with two subtypes within the heathland type.

1. Heathland: 1a. wet (Sphagnum) subtype
 - 1b. Dry (Ledum) subtype
2. Pine Woodland
3. Birch Woodland
4. Spiraea Brushland
5. Mixed Coniferous Woodland
6. Salmonberry Bushland
7. Alder Woodland
8. Unvegetated Peatland.

The quantitative floristic composition of each vegetation type is presented in Appendix - 1. The map of the vegetation types of Burns Bog is shown in Fig. 4 (in pocket at back). Photographs typical of each major vegetation type are also included (Fig. 5).

1. Heathland (Fig. 5a)

Main features:

1. open character, with scrub or small Pinus contorta;
2. shrub storey dominated by heaths (Ericaceae), mainly Ledum groenlandicum;
- 3a. wet (Sphagnum) subtype - numerous mats and hummocks of Sphagnum spp.;

Figure 5: Photographs illustrating the major vegetation types of Burns Bog.

- a) Heathland (wet subtype in foreground)
- b) Pine Woodland
- c) Birch Woodland (dense stands of young birch)
- d) Spiraea Brushland (shrubs in foreground)
- e) Mixed Coniferous Woodland
- f) Alder Woodland (mixed with birch)

The dense growth of Salmonberry Bushland made it impossible to obtain a representative photograph. No photograph of Unvegetated Peatland is included.



- 3b. dry (Ledum) subtype - few hummocks or mats
of Sphagnum spp.

Heathland vegetation occupies the central portion of the bog (Fig. 4) and covers the greatest area of all the vegetation types. Outliers of this assemblage are also found near the edges of the bog as open islands in pine woodland. Sphagno-fibrisol soils characterize this vegetation type (Luttmerding and Sprout, 1969). Drainage is poor and the water table is never more than a few centimeters below the surface.

Heathland vegetation is divisible into two subtypes; wet (Sphagnum) heathland and dry heathland. Most of the wet, central area of the bog falls into the Sphagnum heathland category and represents typical raised bog conditions characterized by prolific growth of Sphagnum spp. Dry (Ledum) heathland occupies recently burned-over sites within and around the raised, central area. Extensive stands of Ledum groenlandicum cover these areas, and little Sphagnum cover is present. These two subtypes are recognizable locally in the field, but cannot be distinguished in the air photographic mosaic used to map the vegetation.

1a. Wet (Sphagnum) heathland

There is no significant tree overstorey in Sphagnum heathland. Stunted Pinus contorta with growth rates of around 1 cm diameter every 15 years is abundant. Occasional dwarfed specimens of Tsuga heterophylla and Betula occidentalis also occur.

The shrub layer consists chiefly of Ericaceae. Ledum groenlandicum and Vaccinium uliginosum are the dominant species. Ledum, occupying the

relatively dry sites, is the more abundant of the two, whereas V. uliginosum favours wetter spots, particularly the transitional habitat between Sphagnum hummocks and depressions. Vaccinium myrtilloides and Gaultheria shallon frequently thrive in dry sites under taller (3-10 m) pines. Kalmia microphylla subsp. occidentalis and Andromeda polifolia favour wetter conditions. Empetrum nigrum grows in all but the wettest sites.

The herb layer is best developed in hygric depressions. Here, Rhynchospora alba and scattered Eriophorum chamissonis thrive, with sporadic Dulichium arundinaceum. Sphagnum mats and hummocks support Vaccinium oxycoccos, Rubus chamaemorus and Drosera rotundifolia. Tofieldia glutinosa and Drosera anglica grow in a restricted area in the central bog. These two taxa were probably more widespread before draining and peat mining activities decimated the populations. Nuphar lutea occupies pools choked by Sphagnum.

The ground cover consists principally of Sphagnum spp. with Sphagnum capillaceum predominating. This moss tolerates the driest conditions of all the sphagna of this vegetation type and is presently actively advancing into dry heathland and Pine Woodland along a large front in the southern sector of the bog. Sphagnum fuscum flourishes best under slightly wetter conditions and combines with S. capillaceum to form extensive mat-hummock complexes. Sphagnum recurvum var. tenue floats along with Nuphar lutea in depressions where standing water is present throughout the year. In shallow, flat-bottomed hollows that dry out in summer and autumn, Sphagnum tenellum usually forms a monospecific carpet. Sphagnum papillosum develops best

under a moisture regime intermediate between that preferred by S. capillaceum/S. fuscum and S. recurvum/S. tenellum. S. papillosum is a major hummock-forming species in the central bog.

Other mosses occur in wet heathland, but are less abundant than in dry heathland. Polytrichum juniperinum, however, often crowns the tops of Sphagnum hummocks. Two characteristic bog liverworts, Mylia anomala and Gymnocolea inflata, grow interspersed among the sphagna.

Lichens are a major element of the ground cover type. Two lichen species, Cladina mitis and Cladina rangiferina, typically form cushions on hummock tops.

1b. Dry (Ledum) heathland

This subtype can be best envisaged as a monoculture of Ledum groenlandicum, which forms an almost continuous shrub storey, interrupted here and there by Vaccinium myrtilloides. Most of the other species characteristic of wet heathland are also present but in fewer numbers. Pinus contorta is either absent or represented only by young saplings. Thickets of Spiraea douglasii and Myrica gale along with Pteridium aquilinum bracken grow where dry heathland reaches the edges of the bog, and indicate both more humic and slightly drier conditions.

The herb stratum is very poorly developed. Instead there is often an abundance of mosses and lichens. Polytrichum juniperinum forms extensive mats on disturbed peat. Aulacomnium androgynum grows near rotting wood. The following species form colonies among heath stems and under Pinus:

Dicranum scoparium

Stokesiella oregana

Hylocomium splendens

Pleurozium schreberi

Rhytidiadelphus loreus

Rhytidiadelphus triquetrus

Lichens grow primarily on the dry surface layer of heath peat that often contains charcoal. Cladonia cenotea, Cladonia chlorophaea, Cladonia subsquamosa and Cladonia transcendens thrive under these conditions.

2. Pine Woodland (Fig. 5b)

Main features:

1. stands of Pinus contorta greater than 4 m high;
2. shrub layer dominated by Ledum groenlandicum and Gaultheria shallon;
3. medium to well developed bryophyte cover.

Pine Woodland forms a band of vegetation surrounding the central mass of Heathland. Typic mesisol soils are characteristic (Luttmerding and Sprout, 1969). The water table can vary as much as 1 m, and drops well below the surface in late summer.

The closed to partially open tree stratum is composed of Pinus contorta, usually much taller than 4 m. Growth rates, as noted in tree rings from transverse sections, range from 1-6 years for each centimeter of diameter, a rate much higher than in Heathland. Tsuga heterophylla and Betula occidentalis are present in a few sites.

The shrub layer, dominated by Ledum and Gaultheria is usually well developed, whereas Vaccinium myrtilloides is locally abundant. Spiraea douglasii and Pteridium aquilinum grow primarily in the transition to birch woodland. Heathland species such as Vaccinium uliginosum, Kalmia microphylla, and Vaccinium oxycoccos occupy sites where sphagnum mosses appear to be advancing.

In wet areas the herb layer consists of the same species as those found in wet heathland. In several sites Trientalis europaea subsp. arctica, Cornus unalaschkensis and Carex lenticularis occur in patches.

Sphagnum mosses (S. capillaceum, S. papillosum) are characteristic of the transition to wet heathland. In the rest of the Pine Woodland, mosses characteristic of dry heathland abound, at times forming extensive carpets.

3. Birch Woodland (Fig. 5c)

Main features:

1. dense stands of mature Betula occidentalis;
2. shrub storey of Spiraea douglasii;
3. profuse growth of Pteridium aquilinum.

Birch Woodland surrounds the bog proper, in places alternating with Spiraea Brushland. The poorly drained soils, composed of well decomposed organic matter, are classified as typic humisols (Luttmerding and Sprout, 1969).

Betula occidentalis dominates the tree stratum, with Pinus contorta and Salix hookeriana occasionally interspersed.

In the understorey, Spiraea and Pteridium grow in great numbers. Locally Gaultheria sometimes dominates. Rubus spectabilis, Ledum groenlandicum and Myrica gale appear sporadically.

Carex rostrata, Carex lenticularis, Trientalis europaea and Cornus unalaschkensis constitute most of the impoverished herb layer. The same moss species are present as in Pine Woodland, of which Polytrichum juniperinum, Polytrichum commune, and Isoetecium spiculiferum are the most abundant.

4. Spiraea Brushland (Fig. 5d)

Main features:

1. absence of a tree stratum;
2. dense thickets of Spiraea douglasii;
3. sparse herb-bryophyte cover.

This vegetation type surrounds most of Burns Bog. As in Birch Woodland, the substrate is a typic humisol (Luttmerding and Sprout, 1969).

In this zone, dense thickets of Spiraea predominate over all species. Betula occidentalis and Malus fusca occur as isolated individuals. In the transition regions into bog vegetation types, Gaultheria shallon, Ledum groenlandicum and Myrica gale appear. Usually only Trientalis europaea grows in the herb layer. Moss growth is also suppressed, with only Polytrichum juniperinum reaching appreciable cover values.

This Spiraea Brushland vegetation type is also common on the wetlands of the Fraser River Delta. Around the bog, it seems to occupy the position of a poorly defined lagg, a situation also characteristic of a number of other west coast bogs (Rigg and Richardson, 1938).

5. Mixed Coniferous Woodland (Fig. 5e)

Main features:

1. a canopy of Thuja plicata, Picea sitchensis, Tsuga heterophylla and, in places, Alnus rubra;
2. a shrub layer dominated by Gaultheria shallon, Rubus spectabilis, and Menziesia ferruginea;
3. abundant Lysichitum americanum;
4. extensive bryophyte cover.

The Mixed Coniferous Woodland is best developed in the eastern section of the bog along the foot of Panorama Ridge. Remnants of this vegetation

type also border Crescent Slough. The humic mesisol (Luttmerding and Sprout, 1969) soil is usually saturated, resulting in swampy conditions.

The upper storey consists mainly of mature Thuja plicata, Picea sitchensis and Tsuga heterophylla. One recently felled Picea specimen, measuring 80 cm in diameter, was determined to be 515 years old. There are also some large Pinus contorta that are 30 cm in diameter and up to 125 years old. The most abundant, tall, deciduous trees are Alnus rubra and Betula occidentalis. Alnus seems to be restricted to sites where there is a mineral horizon within 1-2 m of the surface. In several areas there is a shrubby tree/tall shrub stratum including in most cases Rhamnus purshianus, Acer circinatum, Cornus sericea and the occasional Viburnum edule.

Within this vegetation type there is a dense shrub layer, usually dominated by Gaultheria shallon, with lesser numbers of Menziesia, Rubus spectabilis, Spiraea douglasii, Vaccinium ovalifolium and Vaccinium alaskaense. Vaccinium parvifolium is usually limited to rotting stumps.

The herb stratum of Mixed Coniferous Woodland is dominated by Lysichitum americanum, which reaches densities of 90 individuals per 100 m². Athyrium filix-femina and Dryopteris assimilis sometimes occur in association with Lysichitum.

Mosses and liverworts cover much of the ground, logs and tree trunks.

The most common of these are:

Rhytidiadelphus loreus

Stokesiella oregana

Mnium glabrescens

Isoetecium spiculiferum

Hylocomium splendens

Frullania tamarisci

Pellia neesiana

Scapania bolanderi.

6. Salmonberry Bushland

Main features:

1. Irregularly developed tree canopy;
2. dense small tree/tall shrub layer, dominated by
Rubus spectabilis (Salmonberry);
3. well developed bryophyte carpet.

The removal of large trees by logging from Mixed Coniferous Woodland in the eastern part of the bog has resulted in the growth of rather dense stands of Rubus spectabilis. The soil is a humic mesisol (Luttmerding and Sprout, 1969).

The common tree species that remained or colonized after logging include:

Picea sitchensis

Thuja plicata

Tsuga heterophylla

Alnus rubra

Betula occidentalis

Malus fusca

Rhamnus purshianus

Salix lasiandra.

Although Rubus spectabilis dominates the shrub storey, there are other shrub species also present, including:

Cornus sericea

Gaultheria shallon

Lonicera involucrata

Menziesia ferruginea

Sambucus racemosa

Spiraea douglasii

Vaccinium ovalifolium

Vaccinium parvifolium.

Lysichitum americanum is the most abundant member of the poorly developed herb stratum. There are also scattered plants of Maianthemum dilatatum, Oenanthe sarmentosa, Scutellaria lateriflora and Stellaria crispa.

The large number of old logs in this vegetation type has contributed to an extensive bryophyte cover. The species found are those that are also characteristic of the Mixed Coniferous Woodland (see previous vegetation type).

7. Alder Woodland (Fig. 5f)

Main features:

1. an Alnus rubra canopy;
2. a shrub stratum characterized by Rubus spectabilis;
3. sparsely developed herb and bryophyte strata.

Alder Woodland has developed on a logged alluvial fan, deposited by a small creek flowing off Panorama Ridge. The soils under Alder Woodland were originally mapped as humic mesisols (Luttmerding and Sprout, 1969). However, on field checking, the soils appear to contain abundant mineral material, often within a few centimeters of the surface and thus are not organic in nature.

The canopy is composed chiefly of Alnus rubra, with the occasional Salix lasiandra. Other tree species occurring in the assemblage are:

Picea sitchensis

Thuja plicata

Acer circinatum

Betula occidentalis

Malus fusca

Rhamnus purshianus.

Rubus spectabilis is the most common shrub. The following occur sparsely:

Lonicera involucrata

Menziesia ferruginea

Sambucus racemosa

Vaccinium parvifolium

Viburnum edule.

The shaded conditions restrict the growth of herbs, and only Claytonia sibirica and Stellaria crispa provide any appreciable cover. The bryophyte stratum is similar in composition but less developed than that of Mixed Coniferous Woodland.

8. Unvegetated Peatland

Peat has been extracted from a large area in the center of Burns Bog since early in the 20th century (Biggs, 1976). Currently, large areas are being mined by either the hydraulic method or the "scratching" method. Both of these practices produce large expanses of bare peat. In areas mined by the hydraulic method, large excavated pools are left behind with ridges of

original vegetation in between. The scratching method consists of annually removing the top 8 cm of dry surface peat from extensive plots that remain vegetation-free. When an area is finally abandoned, it slowly recolonizes into a typical Sphagnum heathland, with an assemblage initially including Polytrichum juniperinum, Rubus chamaemorus and Rhynchospora alba.

The Original Vegetation of the Burns Bog Area

Although the plant assemblages of the central bog are probably representative of the original vegetation cover, the peripheral areas are badly disturbed as a result of clearing, draining and burning since European immigration. Knowledge of the original vegetation can provide clues to the successional phases in the development of Burns Bog as well as identifying neighbouring pollen sources that were potential contributors to the palynological assemblages found in cores. Data for reconstructing pre-disturbance plant cover can be obtained from early Land Survey Records (cf. Janssen, 1967). Surveyors mapping the Fraser Delta in the early 1870's provided notes on the vegetation in the area around Burns Bog, although they did not survey within the bog. North and Teversham (1977) have synthesized these data into a map showing the original vegetation. Despite problems in interpretation of some of the surveyors' terms for plants, North and Teversham were able to recognize 28 vegetation types based mainly on physiognomic characters. In the map they prepared, vegetation units were not outlined; the occurrence of a vegetation type at a locality was simply denoted on a map of the Fraser Lowland, by a letter designated to represent that type.

For the purposes of the present study, the map of North and Teversham, along with some of the original information from an early map (Scott, Pinder and Cridge, unpublished) containing surveyors' notes,

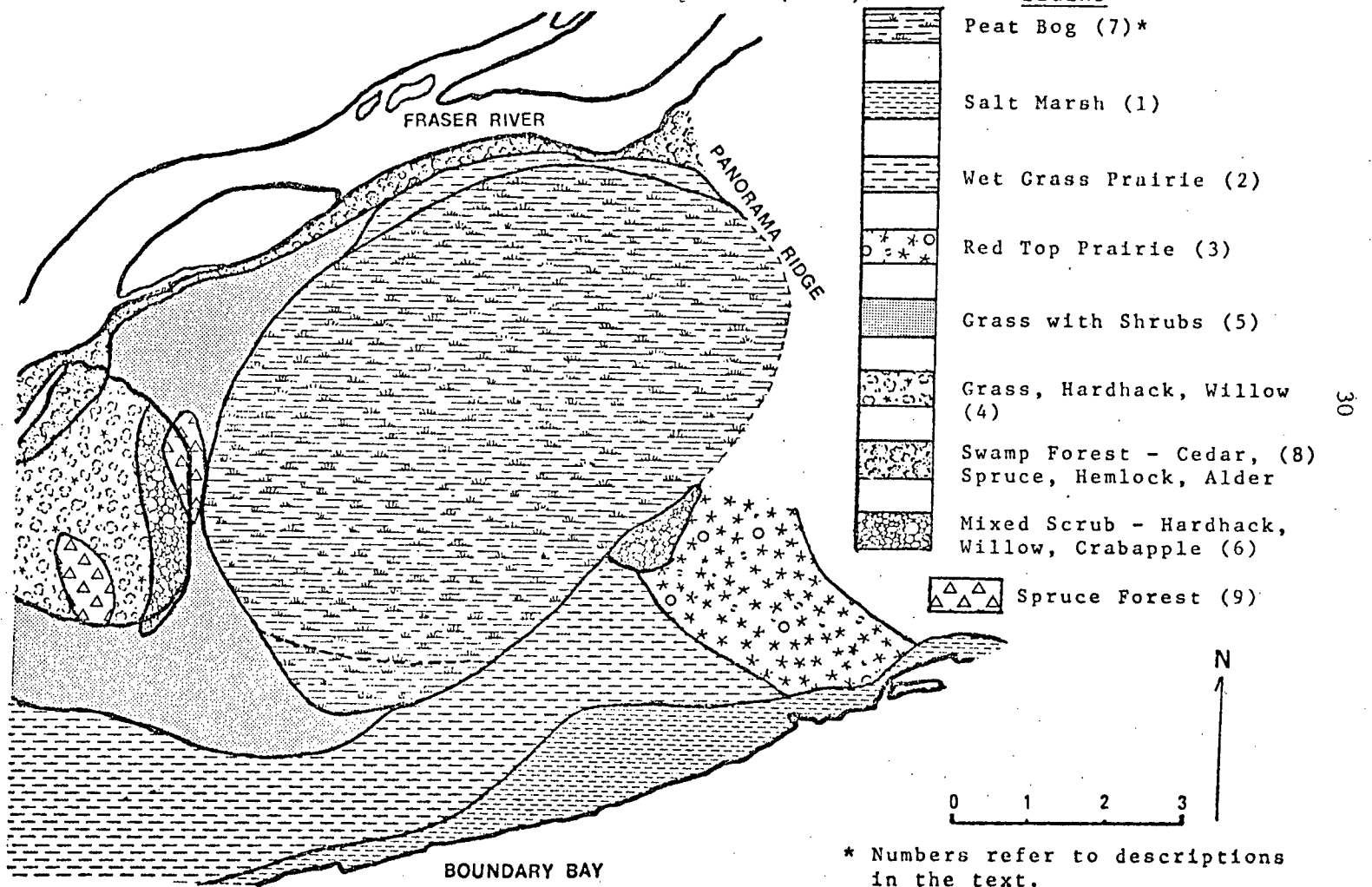
has been used to produce a map of the vegetation zones extant in the Burns Bog area in 1873-1874 (Fig. 6). Some interpretation and generalization of the data are made here, so that boundaries and descriptions must be considered very approximate. Descriptions of the vegetation types are mostly those used by North and Teversham (1977), and come directly from surveyors' reports.

The map:

Nine vegetation types are recognized for the Burns Bog area and plotted on the map:

1. Salt marsh - containing saltgrass, probably same as current salt marsh vegetation.
2. Wet grass prairie - bunchgrasses, rushes and reeds interspersed, probably containing sedges also; no current equivalent.
3. Red top prairie - coastal grassland, may have contained Agrostis sp.; no known current equivalent.
4. Grass, hardhack and willow.
5. Grass with shrubs - mainly grass with patches of willow, hardhack, crabapple and rose.
6. Mixed scrub - hardhack, willow, crabapple, rose; common wetland vegetation type in the Fraser Delta, perhaps similar to Spiraea Brushland (Ch. 2).
7. Bog - small withered pines, cranberry bush, moss; labrador tea around the edges in places; equivalent with current Heathland vegetation type (Ch. 2).

FIGURE - 6: Original vegetation of the Burns Bog area (1873).



8. Swamp forest - cedar, spruce, hemlock, alder, willow, crabapple; similar to Mixed Coniferous Forest (Ch. 2).
9. Spruce forest - somewhat swampy; spruce, crabapple, willow, alder, briars, vine maple; similar to current river bank vegetation.

The map reveals remarkable differences between the original and the present vegetation of the bog (Fig. 4). At the time of the survey, Pine Woodland and Birch Woodland did not exist. The areas they now occupy then supported a Heathland or bog type vegetation. This is substantiated by the observation that no specimens of Pinus contorta within the Pine Woodland have been found to be over 70 years old. Also within a few centimeters of the surface, typical Sphagnum peat is present under the Pine Woodland and much of the Birch Woodland.

These two vegetation types have probably originated as a result of clearing, burning and draining. Biggs (1976) and Osvald (1933) both refer to clearing and burning of the southern parts of the bog.

The farmland regions to the south of the bog were covered by wet grassland containing bunchgrasses, rushes and reeds. Significantly, no mention is made of sedges here or in any of the wetland environments and it is probable that surveyors lumped sedges along with grasses in their descriptions. To the east, there was good grass prairie, classified into the red top prairie vegetation type by North and Teversham (1977). Bordering the bog on the west and north, shrubs were an important part of the vegetation, occurring in clumps among grasses (types 4 and 5) or in thickets (mixed scrub). Hardhack (Spiraea douglasii) seems to have been one of the dominant

species involved. Some spruce forest grew along Crescent Slough. Swamp forest occupied the banks of the Fraser River.

In short, the area was apparently covered largely by bog vegetation with considerable zones of wet grassland, intermediate grass and shrubs and shrubby thickets. Both the Birch and Pine Woodland zones appear to have developed in relatively recent times.

The Role of Fire in Burns Bog

Fires have been documented in Burns Bog since the late 19th century (North and Teversham, 1977; Osvald, 1933). As recently as August 1975, there was a major fire in the northern sector of Burns Bog. Fires are recorded in the cores as charcoal horizons. An understanding of the role of fire in bog ecology is necessary for interpreting sections of pollen diagrams and explaining some of the current features of the vegetation.

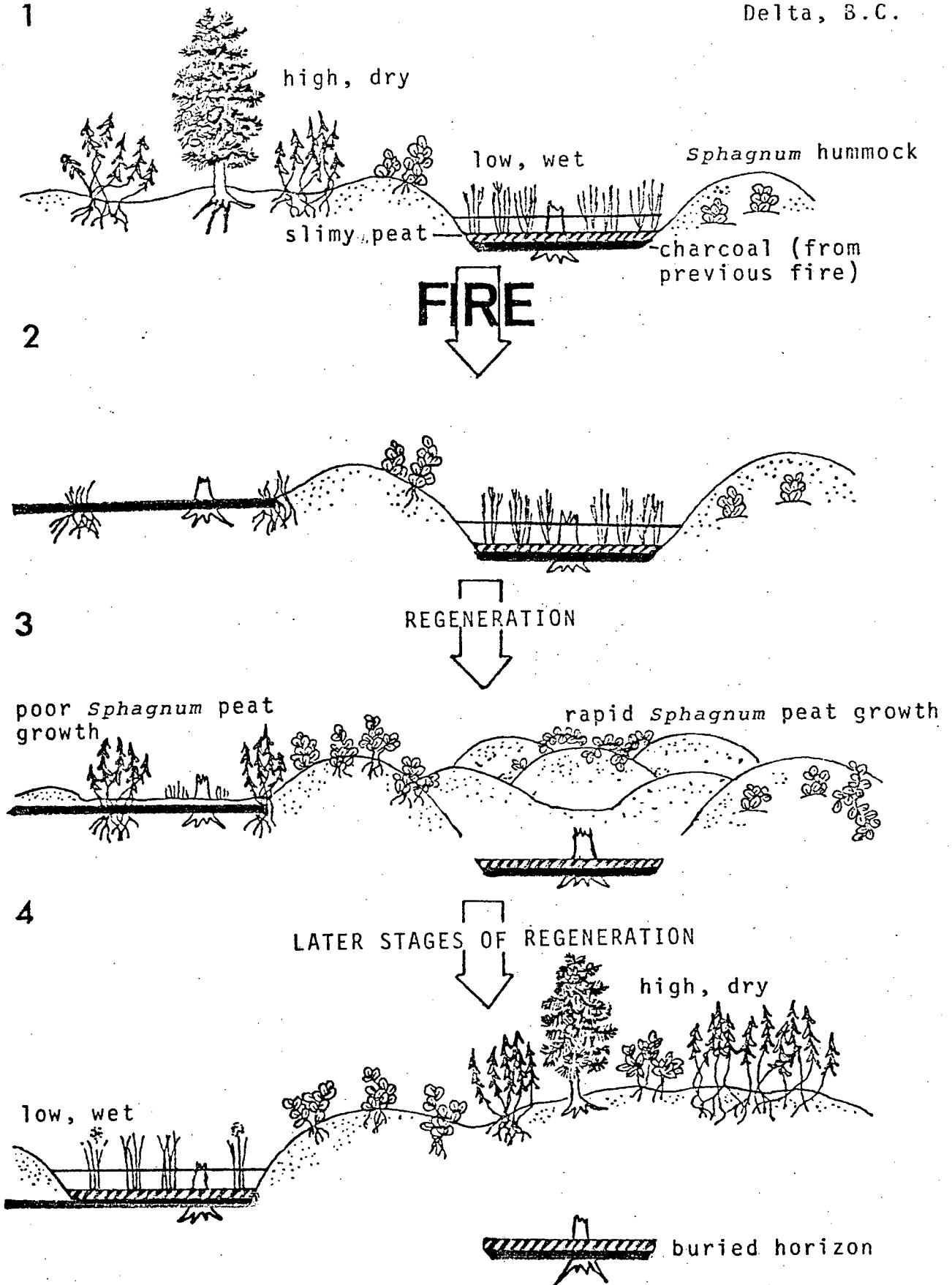
The importance of fires in bog development first became apparent when two types of wet depression were identified in the bog. One type of depression is .5-1 m deep and is choked with Nuphar lutea and Sphagnum recurvum. The Sphagnum papillosum flanks of these "Nuphar ponds" descend steeply into the water which persists throughout the year. These are the typical depressions that characterize many of the bogs of southwestern B. C. (Osvald, 1933) and are probably related to normal raised bog growth. The second type of depression is shallow (.2 m), dries out in the summer and has a firm flat bottom. It is characterized by a feeble carpet of Sphagnum tenellum and extensive growth of Rhynchospora alba. The sides of these "Rhynchospora lows" grade gradually into hummocks of Sphagnum capillaceum and Sphagnum fuscum. They also often contain pine stumps. Both types of depression occur within a few yards of each other.

A significant feature of "Rhynchospora lows" is that within the top .15 m of the surface of the bottom deposits there is always a thick (up to 2 cm) layer of charcoal. Shallow pits dug in shrubby vegetation beside these "Rhynchospora lows" did not reveal a similar charcoal layer. As a result, the scheme outlined in Fig. 7 was originally conceived as a possible explanation for the development of "Rhynchospora lows". This scheme was later confirmed after observations of the area burned in August 1975.

The undisturbed bog surface is a mosaic of wet, Sphagnum-dominated and dry, shrub-dominated patches; that is, a mosaic of Sphagnum heathland and dry (Ledum) heathland. Many of the depressions in the Sphagnum heathland are sufficiently wet that they do not support any shrub growth. The shrubby vegetation of the dry heathland, dominated by Pinus contorta and Ledum groenlandicum, seems predisposed to fire. The dense, low growth form of the Pinus, with many dead branches, provides ideal conditions for the ignition and spread of fire (Rowe and Scotter, 1973). Similarly, Ledum seems ideally suited for fire because it produces great numbers of tinder-like stems and also because of its high oil content, a characteristic shared by many fire-adapted plants (pyrophiles) (Main, 1976). Burning of dry leaves of Ledum in the lab showed that this oil would appear on the leaf surface and sizzle into flame. Ledum and many other shrubby bog plants have extensive root crown systems that regenerate after fire, and set aerial stems within a short time.

After a fire has burned over the bog surface, most of the shrubby vegetation is destroyed along with any Sphagnum growing among the stems. However, the wet depressions are left untouched because there are no shrubs to carry the flames over. Hence, after a fire, a desolate wasteland,

FIGURE - 7: Fire-induced hummock-hollow cycling in Burns Bog,
Delta, B.C.



dotted with patches of unburned Sphagnum; is left behind. These Sphagnum islands then serve as centers of Sphagnum expansion over the surrounding, charred surface. They also become the centers of Sphagnum peat accumulation, resulting in the elevation of these sites above the surrounding area.

In contrast to this, Sphagnum colonization of the relatively flat, burned surface is slow. Although small cushions form from Sphagnum disseminules (spores and plant fragments), the colonies do not spread quickly. Observations indicate that about 20 years after a fire, cushions of Sphagnum capillaceum and Sphagnum papillosum were only sparsely scattered and only 15-30 cm in diameter.

Initially, the burned areas are quickly revegetated from root crowns of shrubs, of which Vaccinium myrtilloides is the first to dominate, followed by a massive proliferation of Ledum. Observations made one year after the August 1975 fire, indicated that along with these shrubs Polytrichum juniperinum, Funaria hygrometrica, and Aulacomnium androgynum quickly colonized the burned substrate. Marchantia polymorpha, absent at other times in the bog, appeared abundantly in very wet spots. This bryophyte phase is a common post-fire phenomenon in European bogs (Froment, 1975) and in the boreal forest (Rowe and Scotter, 1973).

Heath peat accumulation under these conditions is very slow (approximately 1 mm per year based on one observation) because decomposition seems almost to keep pace with heath litter deposition. The result is that these formerly shrubby areas become lower than the unburned, actively growing, Sphagnum islands. Thus many spots, especially those where the fire has burned into the peat substrate, become shallow, water-filled depressions with a charcoal base. These "lows" are eventually colonized by Rhyncho-

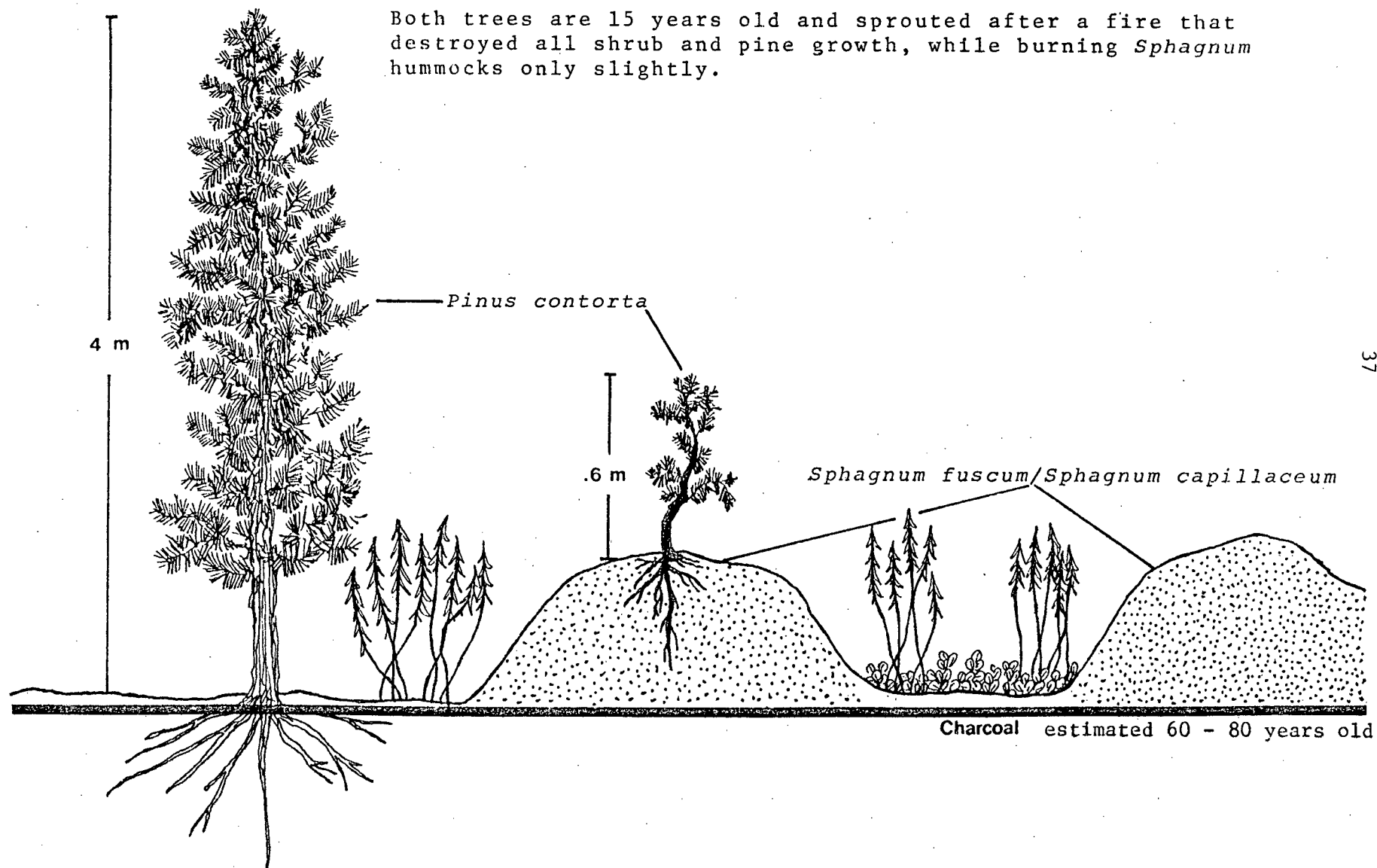
spora alba, Sphagnum tenellum and algae. In time a "Rhynchospora low" results; because it is wetter than the surrounding area, it eventually converts to a center for Sphagnum growth and peat accumulation. Thus a cycle of hummock-hollow alternation, a mechanism at least partially responsible for raised bog growth, is continued. It is questionable whether this cyclic process necessarily speeds up peat accumulation, because; a) it may remove considerable amounts of previously accumulated peat; and b) burned-over areas initially accumulate peat very slowly compared to sites with active Sphagnum growth. Thus, interruption of natural Sphagnum cycling by fire may severely retard normal peat accumulation.

After the initial Polytrichum-shrub stage, but before Sphagnum growth, lichens of the genus Cladonia move in and blanket extensive areas. For example, a section of Burns Bog burned around 1955 is characterized by very high cover values for Cladonia spp. This is a feature also commonly observed in the boreal forest following fire (Rowe and Scotter, 1973). The small amount of peat produced by these has a slimy character and contains many fungal hyphae.

The Effect of Sphagnum on Pine Growth

Pinus contorta seedlings sometimes emerge as early as one year after a fire, but the interval for their appearance is usually 2-5 years later. Those Pinus seedlings that have landed on unburned Sphagnum hummocks or mats grow very poorly (1 cm diameter every 15 years), and develop a stunted stature (.6m high) (Fig. 8). Those that germinate on burned surfaces (even if they are wet) grow relatively well (1 cm diameter every 1-6 years) and appear normal (4 m high). Pinus seedlings with part of the root systems

FIGURE - 8: Relationship of pine growth to Sphagnum hummock formation.



covered by an actively growing Sphagnum patch exhibit intermediate features with progressive reduction of ring growth on the side of the trunk that faces the advancing hummock. This pattern is probably correlated with the highly competitive ability of hummock-forming mosses, such as Sphagnum capillaceum, to absorb nutrients (Moore and Bellamy, 1974).

This hypothesis may also explain a surprising periodicity of 10-20 years in ring growth found in certain buried Pinus stumps. Local increased growth of hummock-forming sphagnum mosses would result in a period of poor growth, whereas a decrease or standstill in Sphagnum would result in improved growth.

Summary

In summary, the modern composition and distribution of the vegetation of the bog appears to relate to changes that have occurred in the original vegetation. Clearing of land and alteration of drainage patterns have led to the development of Pine Woodland and Birch Woodland on Sphagnum peats around the bog. Wet grassland and shrubland communities of a possible successional nature were present around the bog. Finally the impact of fire on the bog ecosystem was discussed showing that it caused a sudden change in vegetation that was reflected in sediments by a decrease in rate and change in nature of peat accumulation.

CHAPTER 3: BOG ERICACEAE: POLLEN TETRAD SIZE, POLLEN PRODUCTIVITY

Members of the Ericaceae and Empetrum nigrum are important components of bog vegetation, particularly in Burns Bog. As such, it would be of considerable value to know the role ericads have played in bog development. To gain as much information as possible from pollen diagrams, studies were made of:

1. diameter ranges of ericad pollen tetrads;
2. the pollen productivity of these bog ericads.

The results of both studies have been applied to the reconstruction of the vegetation of those intervals containing sufficient amounts of ericaceous pollen.

1. Tetrad Diameter of Bog Ericaceae and Empetrum nigrum

The pollen of the Ericaceae and Empetrum is preserved in varying amounts in bog deposits, but unfortunately it is difficult to identify the various genera, and even more difficult to identify the species (Oldfield, 1959). In the present study, a rudimentary, but quick system utilizing tetrad diameter was developed to distinguish ecologically significant groups of species in Burns Bog.

The ericad species found abundantly in Burns Bog are:

Ledum groenlandicum

Kalmia microphylla var. occidentalis

Andromeda polifolia

Vaccinium myrtilloides

Vaccinium oxycoccos

Vaccinium uliginosum

Gaultheria shallon

Empetrum nigrum.

Diameter measurements (see Oldfield, 1959) were made on 100 acetolyzed tetrads taken from flowers collected from numerous plants at various localities in Burns Bog. The results are presented in Table 1 and the size distribution for each group is plotted in Fig. 9.

Three diameter groups can be distinguished:

1. less than 30 μm - including most of Ledum and Empetrum tetrads;
2. 30-36 μm - including mainly Kalmia microphylla and Vaccinium myrtilloides tetrads;
3. greater than 36 μm - including Vaccinium oxycoccos, Vaccinium uliginosum, Andromeda polifolia, and Gaultheria shallon tetrads.

Fortuitously, these groups of species have ecologic significance and can be used to indicate:

- Group 1. - dry (Ledum) heathland conditions;
- Group 2. - intermediate to wet conditions;
- Group 3. - very wet (Sphagnum) heathland conditions.

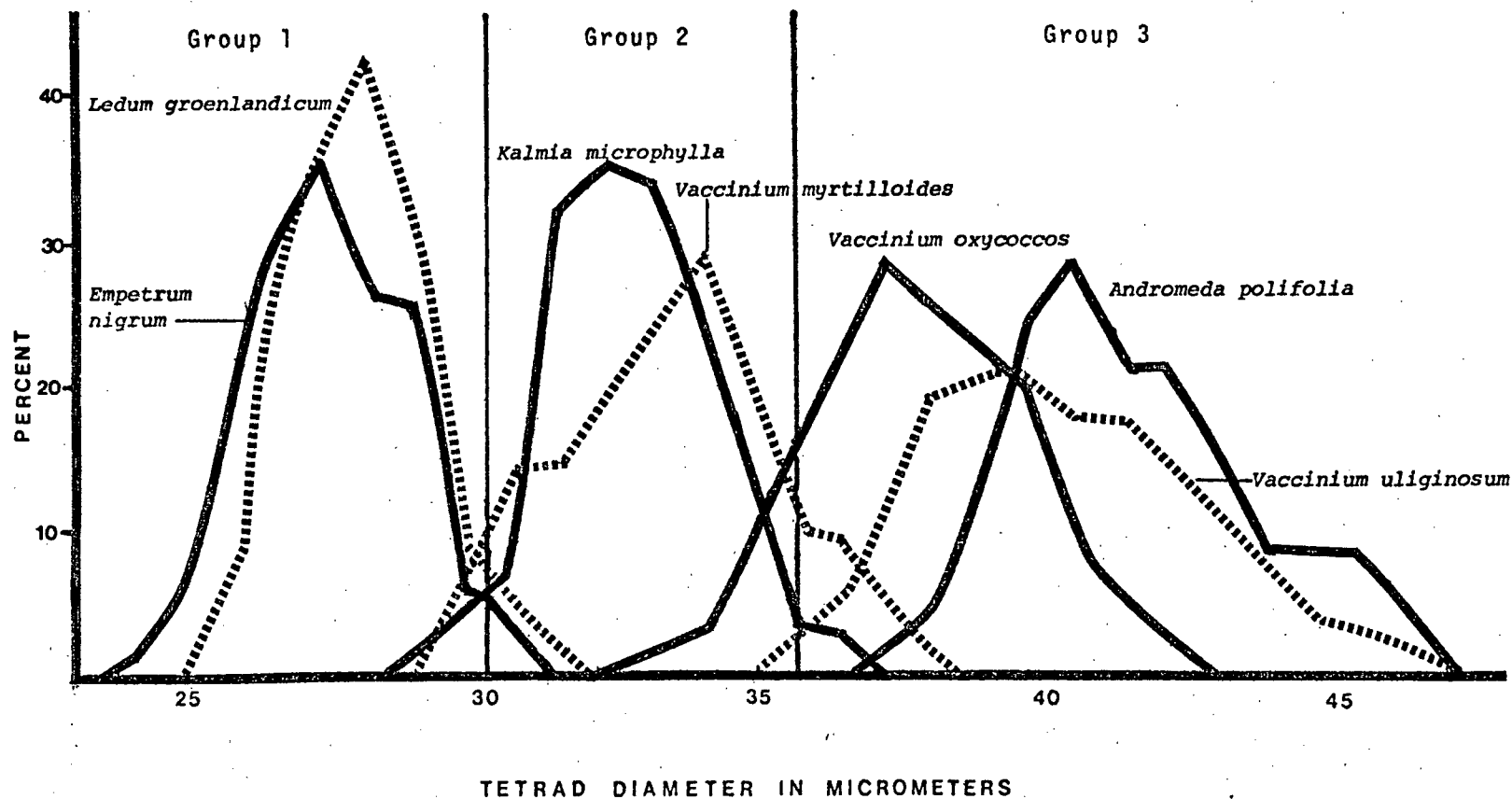
Ledum groenlandicum of Group 1 is the prime indicator of dry (Ledum) heathland conditions in the bog (see Ch. 2), and flowers profusely in these relatively dry sites. Empetrum nigrum, on the other hand, is not necessarily an indicator of dry situations since it can grow well among Sphagnum hummocks. However, in this wetter habitat it has been observed to flower poorly (cf. Birks, 1975). Secondly, under conditions of ideal preservation,

TABLE 1: TETRAD DIAMETERS OF MAJOR ERICAD SPECIES IN BURNS BOG, DELTA, B. C.

<u>Species</u>	<u>Mean tetrad diameter</u>	<u>Range</u>	<u>Standard Deviation</u>
<i>Ledum groenlandicum</i>	27.20 μm^*	24-30	1.41
<i>Empetrum nigrum</i>	26.15	22-31	1.77
<i>Kalmia microphylla</i> subsp. <i>occidentalis</i>	32.54	28-37	1.75
<i>Vaccinium myrtilloides</i>	33.21	28-39	2.46
<i>Vaccinium oxycoccos</i>	38.63	33-44	2.24
<i>Vaccinium uliginosum</i>	41.78	36-48	2.83
<i>Andromeda polifolia</i>	43.29	38-51	2.64
<i>Gaultheria shallon</i>	46.97	41-53	2.50

*All measurements are in μm . Sample size for all species was 100 tetrads.

FIGURE - 9: Distribution of tetrad sizes of bog Ericaceae and Empetrum nigrum.



Sample size for each species is 100 tetrads.

Broken lines are used for purposes of clarity in presentation and have no other significance.

its tetrads can be distinguished morphologically from those of Ledum.

Kalmia microphylla is the indicator of intermediate conditions in Group 2. Vaccinium myrtilloides is a problematic species in Burns Bog and the Fraser Delta, as its populations are disjunct from the main range in the pine forests of interior British Columbia. Examination of collected material from various sources has not helped clarify whether V. myrtilloides has arrived in the Delta area recently, or if it has grown here ever since suitable conditions became available in these lowland bogs. Vigorous growth and flowering of this plant are restricted to post-fire situations on deep peats where it is not choked out by Ledum.

All taxa of Group 3, except Gaultheria are excellent indicators of very wet conditions, and also of active Sphagnum growth. In contrast, Gaultheria shallon does not grow in very wet habitats, although it is sometimes present on the relatively dry tops of Sphagnum hummocks. It does not usually flower under these conditions and for this reason it has been excluded from further discussion.

Application of results:

The information obtained can be applied to paleoecology by measuring the diameter of tetrads recovered from fossil deposits. Once the frequency of tetrads in each size-range is known, comparison with surface samples permits interpretation of the ericad component of the vegetation.

One assumption must be kept in mind. It is possible that ericaceous species present at one time in the bog may not have survived through to modern times. Hence, caution must be used in interpretation, particularly if there are macrofossils indicating such locally extinct species, or if there are other good indicators of environmental change. Finally the

ecology of each species used needs to be well understood.

For Burns Bog, the species composition and tetrad diameters of ericads correlate well enough to give a good model for interpretation. Although applicable in this case, it does not necessarily follow that this model will work when extended to other bogs, especially those with different species of ericads or different sedimentary regimes.

2. Pollen Productivity of Bog Ericaceae

To increase the usefulness of the three diameter groups in paleoecological interpretation, information on the comparative pollen productivity of the ericad species was also obtained by field sampling. With these data the levels of each ericad group in a fossil pollen sample can be compared, after correcting for differences in productivity.

The pollen productivity per square meter per year was determined for all the species in Table 1, except Empetrum nigrum and Gaultheria shallon. For each species, ten quadrats, 10 cm by 10 cm, were chosen from areas where the highest density of flowers of that species seemed to occur. This provided a maximum productivity value under ideal conditions. In these quadrats the number of flowers was counted and the cover of the species estimated. For each species, the average number of stamens per flower was obtained from 10 flowers. Then, the average number of pollen grains per anther, from a sample of 10 undehisced anthers, was determined. To do this, anthers were placed in a drop of 10% KOH on a glass slide, squashed, and the pollen tetrads dispersed by circular motion of a coverslip. All the pollen tetrads in the anther were counted. Finally, the maximum tetrad productivity per square meter per year was calculated for each species.

From Table 2 it can be noted that Kalmia and Ledum are the most prolific pollen producers. Under optimal conditions they contribute 4.1×10^8 and 3.3×10^8 tetrads/m²/year, respectively, to the pollen crop. V. myrtilloides yields 1.82×10^8 tetrads/m² annually. The remaining three species are relatively poor pollen producers; V. uliginosum at 7.15×10^7 tetrads/m²/year; V. oxycoccus at 5.57×10^7 tetrads/m²/year; and Andromeda polifolia at 2.3×10^7 tetrads/m²/year.

These results indicate that although low percentages of Group 3 tetrads may occur in a fossil ericad assemblage, they are nevertheless significant in terms of the original vegetation cover, because fewer tetrads are produced by this group. In an area dominated by Group 3 vegetation there are often some Ledum (Group 1) and Kalmia (Group 2) plants. On the basis of tetrad productivity, these last two diameter classes could dominate the ericad spectrum. However, as long as a significant portion of the spectrum belonged to the greater than 36 μ m group (for a reasonable sample size), the wet habitat species probably predominated in the heath cover. Also, the results imply that overall percentages of Ericaceae must be expected to be lower in spectra from Group 3 assemblages than in areas dominated by the more productive Group 1 and Group 2 species.

In conclusion, three ecologically significant groups of ericads can be recognized in Burns Bog on the basis of tetrad diameter. When combined with the pollen productivity values for the constituent species of these groups, the plotting of tetrad sizes provides a potentially useful tool for recognizing dry, intermediate and wet heathland vegetation types in fossil deposits.

TABLE 2: POLLEN TETRAD PRODUCTIVITY OF MAJOR BOG ERICACEAE, BURNS BOG, DELTA, B. C.

<u>Species</u>	<u>Flowers per 100 cm²*</u>		<u>Anthers per flower*</u>	<u>Tetrads per anther*</u>		<u>Productivity in tetrads/ m²*</u>	<u>Species cover*</u>
	<u>Mean</u>	<u>Range</u>		<u>Mean</u>	<u>Range</u>		
<i>Andromeda polifolia</i>	73	43-90	10	317	277-428	2.3×10^7	51%
<i>Kalmia microphylla</i> subsp. <i>occidentalis</i>	129	97-180	10	3200	2915-4016	4.1×10^8	56%
<i>Ledum groenlandicum</i>	352	234-455	7	1823	1500-2100	3.3×10^8	95%
<i>Vaccinium oxycoccos</i>	54	39-74	10	1031	881-1152	5.6×10^7	56%
<i>Vaccinium myrtilloides</i>	452	401-500	10	402	264-480	1.8×10^8	91%
<i>Vaccinium uliginosum</i>	95	51-127	10	753	551-865	7.5×10^7	78%

*Means determined for 10 values.

CHAPTER 4: POLLEN DEPOSITION IN WETLAND ENVIRONMENTS OF THE
FRASER RIVER DELTA

Study of surface samples and pollen rain forms an important aspect of Quaternary palynology. Wright (1967) emphasized the value of such investigations in previously unstudied regions and also where vegetation has been disturbed. Cohen (1973) demonstrated that pollen spectra of surface samples provided fingerprints for wetland communities. Such studies indicate that for elucidating local vegetation changes, pollen rain and surface sample data are indispensable, providing the information necessary to relate vegetation to pollen assemblages. In the present study, many surface sample analogs and near-analogs were found for zones recognized in cores. This chapter presents the data and conclusions obtained from palynologic investigations of modern environments and forms the basis for the interpretation of fossil deposits. The work was not intended to be exhaustive, but was used to provide as much critical information as possible to supplement the main paleoecologic research.

A preliminary examination of core BBDC revealed that modern pollen data from salt marsh, intertidal delta-front, river marsh and bog environments would be valuable for assistance in accurate paleoecologic interpretation. To obtain these data three different approaches were used:

1. Pollen rain was monitored at salt marsh and bog sites in the Fraser River Delta during the flowering seasons of 1974 and part of 1976.
2. Cover estimates of species in the vegetation were made at these sites..
3. Multiple surface samples from recently deposited sediments at

these and other locations were analyzed for palynomorphs. A short core, an extension of surface sampling, was taken to provide insight into the developmental sequence at a delta-front site.

Methods

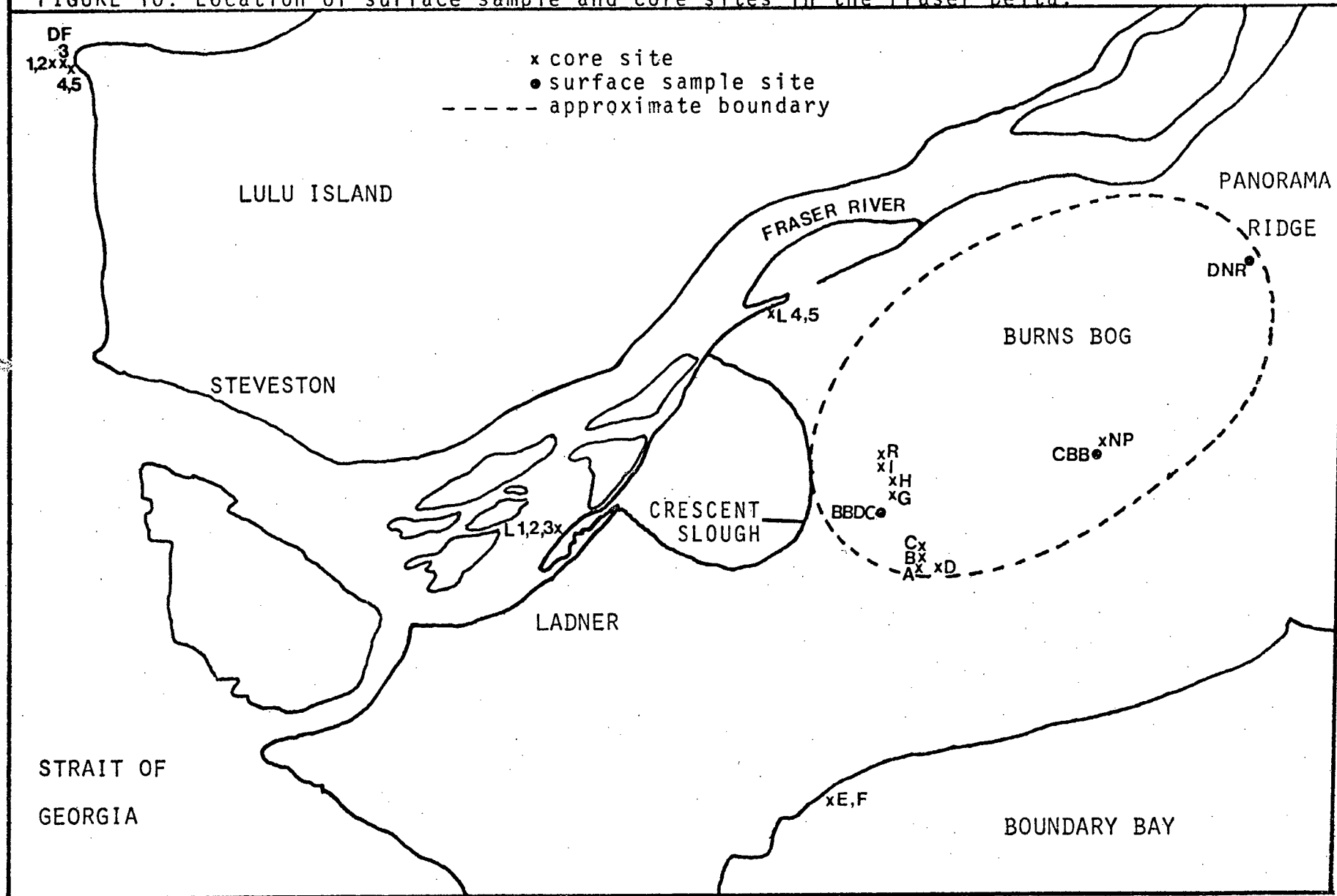
Stations from three areas were chosen for intensive study (Fig. 10). At these localities, pollen rain was monitored, surface samples analyzed and vegetation evaluated. At site R, only pollen rain data were obtained. Surface samples only were collected from site NP, river marsh, and delta-front environments because constant flooding washed away pollen rain sampling dishes and jars. A short core was obtained from a sedge community just outside the dike, south of the Middle Arm of the Fraser River on Lulu Island.

Modern Pollen Rain:

Various sampling methods for pollen rain are available (Lewis and Ogden, 1965). Most are designed to trap pollen above the ground and do not register material dropping directly to the surface from local flowers. This latter component supplies the most precise information for interpreting in situ vegetation.

In the present study, pollen rain was collected initially on glass slides coated with glycerine jelly, and placed in petri dishes. Because of wash-out during rainy periods, the sites had to be visited too frequently, so the use of 100 mm deep glass jars containing glycerin and a few drops of phenol was substituted. Screens were attached over the mouths of the jars to keep out insects and voles (Sorex vagrans vagrans). Jars and dishes were collected at various intervals, ranging from weekly to monthly, as time

FIGURE 10: Location of surface sample and core sites in the Fraser Delta.



permitted.

Contents of jars and petri dishes were rinsed out with hot water and poured through a coarse mesh screen into 15 cc conical centrifuge tubes. The material was then processed by acetolysis, stained and mounted in glycerin jelly on glass slides. Two hundred pollen grains and spores were counted along transects on the slide for each sample.

Surface Samples:

To provide the average pollen and spore composition of the sediments below various vegetation types, 10-20 mm of the surface deposits were sampled with a 20 mm diameter, sharpened aluminum pipe. For sites where pollen rain was also being monitored, three such samples were taken, all within .5 m of the collecting jar or dish, and inside the 2 m x 2 m quadrat evaluated for vegetation. This was done to keep the spatial relations of surface sample, collecting jar and pollen producing vegetation as close as possible. Surface deposits were processed using a standard procedure consisting of HF treatment (when necessary), boiling in 5% potassium hydroxide, acetolysis, bleaching, screening (250 μ m) and staining with safranin. The residue was passed through an alcohol dehydration series into tertiary-butyl alcohol and mounted in silicone oil on glass slides. On the delta-front, just outside the dike, a 1 m core was obtained by pushing a stainless steel sampling tube into the silts. The samples from the core were processed as above.

In all cases, pollen grains and spores were identified and counted along transects of slides, to a total of 200.

Results

The results of pollen rain, surface sample and vegetation analyses are presented and discussed together for each site. All the figures (11-27) and Table 3 containing the results are located at the end of the chapter (pp.

Sites from the Southern Periphery of Burns Bog:

1. Open Betula occidentalis woodland with Pteridium aquilinum understorey (Site A).
2. Ledum groenlandicum heathland in open Pinus contorta woodland (Sites B & C).
3. Spiraea douglasii thickets in open Betula occidentalis woodland (Site D).

1. Open Betula occidentalis woodland with Pteridium aquilinum understorey (Site A).

The site is covered with tall Pteridium aquilinum from June until mid-September. It also contains immature specimens of Spiraea douglasii and Ledum groenlandicum (Fig. 11c). Stands of Betula occidentalis surround the area, providing a cover ranging from 20-100%. The surface is covered by a mat of Pteridium litter throughout the year.

The significant features of the pollen rain (Fig. 11a) are as follows. Alnus, which is part of the regional rain, dominates in late March and early April. This is followed first by a heavy rain of Betula in mid-April, and next by a small peak in cf. Thuja. The Pinus contorta pollen rain is heavy in mid-June, produced mainly by the pine stands 200 m to the north. This Pinus phase is terminated by a gradual rise in Gramineae pollen that appears

to come from wetland stands of Phalaris arundinacea and mixed grasses from agricultural fields to the south. Grass pollen dominates the spectrum until mid-August. During this time, pollen attributed to Rumex cf. acetosella and Chenopodiaceae also occurs, transported into the site from surrounding fields and perhaps from salt marshes in Boundary Bay. Spiraea douglasii pollen, apparently produced by adjacent thickets, ranges from late July to October. In August-September, spores from on-site Pteridium aquilinum appear. Finally, when fern fronds have died down, Betula pollen shows an abrupt increase in September that appears anomalous. This is attributed to birch pollen that has been stirred up from the dry surface by wind, or has fallen along with dead leaves, and deposited in the collecting jars.

Surface samples from site A (Fig. 11b) contain approximately equal quantities (15-20%) of Pinus, Alnus, Betula and Pteridium. These types are well represented in the pollen rain. The relatively high Ericaceae levels seem anomalous as they are absent from both the pollen rain and the vegetation. Possibly, they derived from the peat substrate on which birch woodland has developed. Notable is the low value of Gramineae pollen, so common in the summer pollen rain. Together with the absence of cf. Thuja this suggests that these relatively thin walled grains do not survive on the dried-out fern litter substrate. Thin walled Pteridium spores may be protected in sporangia attached to frond fragments, as fern annuli are present in the surface samples. Abundant quantities of fungal spores (see Table 3), Gelasinospora and Type-3 of Van Geel (V.G. 3) (see Appendix 3, Fig. 51c) are probably indicators of humified litter (Van Geel, 1973).

2. Ledum groenlandicum heathland in open Pinus contorta woodland (Sites B & C).

Sites B and C are located 250 m and 450 m respectively north of site A (Fig. 10) in open Ledum groenlandicum heathland within Pine Woodland vegetation. Both localities are surrounded by dense Ledum (Figs. 12c, 13c), with significant numbers of Vaccinium myrtilloides that are flowering at C, but barely flowering at B. Site C has a considerable cover of Gaultheria shallon, which flowers only poorly. Pteridium aquilinum occurs at both localities.

The pollen rain diagrams from both B and C sites (Figs. 12a, 13a) show reduced Betula peaks compared to site A. The marked decreases in Betula through the site sequence, A, B, C, proceeding away from birch stands, implies that 75% of the pollen is deposited within the first 500 m from the Betula stands. The dispersal distance seems inordinately short especially because of the strong southeasterly winds that blow during this period. Pinus pollen levels are generally higher at sites B and C than at A throughout the summer, presumably because of the proximity of the source trees.

The non-arboreal (NAP) component at sites B and C exhibits reductions in pollen of Gramineae, Rumex cf. acetosella and the Chenopodiaceae derived from farmlands. Apparently this relates to the increased distance of these stations from the edge of the bog. Ericaceae form a prominent part of the summer NAP. In July there is an influx of tetrads less than 30 μm in diameter that are ascribed to Ledum (see Ch. 3). At site C tetrads in the 30-36 μm range originate from whole flowers and anthers, fallen or washed from plants of Vaccinium myrtilloides hanging above the sampling jar. Low levels of Spiraea almost certainly transported from profusely flowering thickets around the bog periphery (cf. Janssen, 1973) are also recorded at

this time. Fewer Pteridium spores are deposited than at site A, reflecting the diminished role of this species in the vegetation.

The surface spectra of sites B and C are dominated by Pinus (Figs. 12b, 13b). Ericaceae tetrads, most of which belong to Ledum, represent the local vegetation dominant. At site C, significant quantities of Alnus and Tsuga are considered to represent the regional pollen component. It is unclear why Alnus reaches much higher levels (25%) at site C than at B. Sphagnum spores in the surface samples at C indicate that the site is situated on a Sphagnum peat substrate.

Fungal microfossils from the surface include V.G. 3, and Microthyriaceae ascocarps. Assulina and cf. Helicosporium rhizopod tests are also present.

3. Spiraea douglasii thickets in open Betula occidentalis woodland (Site D).

Site D was established in extensive thickets of Spiraea douglasii, 150 m east of site A. Spiraea excludes almost all other species, with only Ledum occurring along with it (Fig. 14c). The ground is carpeted with Polytrichum juniperinum.

The pollen-rain diagram for this site (Fig. 14a) resembles that of site A, but differs in having a major Spiraea peak in late July to September. There is no Betula resurgence in late September as at site A; dense growth of Spiraea probably prevents vigorous wind activity at ground level.

Pollen analysis of surface deposits of leaf and twig litter at site D (Fig. 14b) shows substantial numbers of Betula and Spiraea pollen. Significantly, the first sample collected in April contained much more Betula pollen than the two obtained later. This phenomenon was also observed at

site A, and indicates that a number of samples should be taken throughout the year to avoid anomalies arising from coincident sampling time and local pollen production. Alnus percentages are high, especially in comparison to Pinus (15%), even though the pine pollen source is 200 m away, while the Alnus pollen source is at least 2 km distant. Such a sharp decrease in pine pollen within a short distance of the producing vegetation has been observed by Turner (1964), and supports the exponential drop-off model (Janssen, 1973). Spiraea grains appear "melted", most likely as a result of oxidation. Pollen of Nuphar lutea and Sphagnum spores have probably been recycled from disturbed peat under the current vegetation. As at sites A, B and C, grass and other herbaceous species are absent, although they are abundant in the pollen rain. Gelasinospora and traces of Desmidi-
ospora and Assulina are also recorded at site D.

Sites from the Interior of Burns Bog:

1. Pinus contorta woodland (Site H).
2. Sphagnum heathland (Sites I and R).
3. Sphagnum heathland clearing in Pinus contorta woodland (Site G).
4. Nuphar lutea pond in Sphagnum heathland (Site NP).

1. Pinus contorta woodland (Site H).

This station is characterized by a dense stand of Pinus contorta, containing an understorey of Ledum groenlandicum and Vaccinium uliginosum (Fig. 15c).

Throughout the year, the pollen rain is clearly dominated by Pinus, with percentages rarely dropping below 50% (Fig. 15a). Alnus reaches appreciable levels in spring and autumn, when the local Pinus component drops enough to unmask the regional pollen rain. Ericaceae, including

tetrads of all size classes, fall from the surrounding bushes in the summer. The lack of other pollen types reflects the overwhelming local Pinus production, and perhaps also a filtering effect from the crowns of the trees.

The surface spectrum of site H clearly demonstrates that Pinus pollen dilutes all other types (Fig. 15b). Thus high Pinus percentages would be expected to characterize pine woodland vegetation in fossil deposits. Only Alnus and Ericaceae (from plants on the site) contribute significantly. Most Ericaceae tetrads are of the Ledum type although some belong to the greater than 36 μ m size class, reflecting locally abundant Vaccinium uliginosum and Gaultheria shallon. In addition to pollen, the samples contain numerous fungal hyphae and brown, amorphous, organic aggregates. One Assulina test was recorded.

2. Sphagnum heathland (Sites I and R).

These stations are located about 100 m and 300 m respectively, north of the pine woods containing site H. At site I, the sampling jar was placed in a shallow, Sphagnum-lined depression, occupied by Andromeda polifolia, Vaccinium oxycoccos and Vaccinium uliginosum (Fig. 16c). Shoots of Rhynchospora alba are common although they do not constitute a high cover value. Stunted Pinus contorta trees grow around the site. The vegetation at site R is similar to that at site I, but with more V. uliginosum and less Rhynchospora.

In contrast to the situation in pine woodland, Pinus does not dominate the pollen rain diagrams of sites I and R (Figs. 16a, 17). In April and early May, regional arboreal pollen types such as cf. Thuja, Tsuga, Pseudotsuga, Alnus and Betula compose the pollen rain. Large Ericaceae tetrads shed by the heath species at the sites are present during the year. At

site I, cf. Rhynchospora pollen is produced early in August. Much of the pollen arriving in Sphagnum heathland during the summer, e.g. Gramineae, is derived from sources external to the bog. Sphagnum spores are conspicuously absent although Sphagnum spp. completely blanket the ground around site I.

The surface deposits of site I (Fig. 16b) reveal that much of the preserved pollen originated outside the local area. Alnus and Tsuga make up 45% of the total. Pinus, although it produces little pollen at the site, reaches 39% in the collected samples. The Ericaceae, which blanket the ground around the site, comprise only 4% of the pollen spectrum, a case of very pronounced underrepresentation. All of the tetrads were greater than 30 μm in diameter, and most fell into the greater than 36 μm size range. As has been shown in Ch. 3, ericad species producing pollen tetrads in this diameter range are characterized by low pollen productivity values and these surface sample results confirm the prediction of underrepresentation for these species growing at the site.

The absence of Sphagnum spp. spores agrees with the pollen rain results. Irregular Sphagnum spore productivity has been observed by others (Tinsley and Smith, 1973) and seems to be a function of local conditions (Tallis, 1964).

Desmidiospora is preserved abundantly in the Sphagnum peats along with other indeterminate fungal aggregates. The rhizopod cf. Helicosporium is also present. The ecological significance of Desmidiospora is not understood. Since the original description by Thaxter (1891) of Desmidiospora growing on ants under a rotting log, this fungus has remained uninvestigated. This spore type is always associated with Sphagnum/heath peats in

Burns Bog and has been noticed in the same habitat in Camosun Bog, Vancouver, British Columbia (R. J. Bandoni, personal communication). Van Geel (1973), while including a photograph of Desmidospora, was unable to make an identification, nor assign to it specific ecologic conditions.

3. Sphagnum heathland clearing in Pinus contorta woodland (Site G).

This area of active Sphagnum growth is located in a small elongate clearing, 100 m south of site H, surrounded on all sides by dense stands of Pinus contorta. To the north and south, Pine Woodland approaches within 25 m of the site; to the east and west the trees are at least 100 m distant. The vegetation is characterized by heaths (Fig. 18c), growing on and between Sphagnum capillaceum hummocks. Sphagnum recurvum occupies the low, wet inter-hummock areas. Two drainage ditches occur nearby, causing some local alteration of the water table. Although this site is closely associated with pine woods, the pollen rain of this station (Fig. 18a) shows distinctive features, resembling the patterns of sites I and R in Sphagnum heathland. A pronounced peak in Sphagnum spores occurring in late July distinguishes the pollen rain of site G from that of sites I and R.

The surface spectrum of this Sphagnum heathland clearing (Fig. 18b) reveals that Pinus pollen occurs at a much lower percentage than in nearby pine stands (site H). This observation implies that even small clearings in a pine matrix could be recognizable in the fossil record. Ericaceae tetrads fall in the 30-36 μ m group, and are probably those of Kalmia microphylla which grows abundantly at the site (Fig. 32-18c). There are many Sphagnum spores present in the surface samples, in contrast to the other Sphagnum site, I. Desmidospora, indeterminate fungal aggregates, Assulina,

cf. Helicosporium and Actinopeltis abound in the surface deposits.

4. Nuphar lutea pond in Sphagnum heathland (Site NP).

Two surface samples were analyzed from site NP (Fig. 19) to determine whether Nuphar ponds could be differentiated palynologically from other Sphagnum heathland associations. The pond sampled is situated in the central portion of Burns Bog (Fig. 10). Sphagnum recurvum is packed in among the Nuphar plants so that in the dry, late summer the site does not look like a pond. Typical wet habitat heaths, such as Kalmia microphylla, Andromeda polifolia, Vaccinium oxycoccos, and Vaccinium uliginosum approach to within a meter of the sampling site, while Ledum and Pinus grow about 5 m away.

Pinus pollen from local sources and Alnus from the regional arboreal component are the two most abundant types (approximately 30% each). Another regional pollen type, Tsuga, is next in abundance at 12%. Gramineae and Chenopodiaceae pollen, presumably derived from agricultural fields around the bog also occur in significant quantities. Ericaceae are very poorly represented as expected from productivity studies. Nuphar pollen and Sphagnum spores, the two types reflecting the in situ vegetation are recorded in extremely small quantities. This observation supports the principle that interpretations of plant assemblage composition cannot be made on the basis of abundance of pollen types (Cohen, 1973). Characteristic palynologic fingerprints for communities must be obtained from the sediments into which they are incorporated.

Desmidiospora fungal spores, cf. Helicosporium rhizopod tests and Nuphar lutea trichomes were also recorded from the sediments.

Coastal Sites from Boundary Bay:

1. Chenopodiaceae salt marsh (Site E).
2. Coastal grassland (Site F).

1. Chenopodiaceae salt marsh (Site E).

Site E is located 3 km directly south of Burns Bog, at the edge of a very extensive, tidal-flat dominated, shallow bay (Fig. 10). The vegetation around the site is composed of Salicornia virginica, Distichlis spicata, Puccinellia grandis and Plantago maritima (Fig. 21c). Coastal grassland begins 30 m to the north, whereas tidal flats extend to within 10 m in the other directions. Waves, driven by storm winds, inundate the salt marsh periodically.

The pollen rain diagram for site E (Fig. 21a) indicates that arboreal pollen from deltaic and upland trees dominates during the spring, with Alnus (60%) as the major component. In May there is an initial peak in grasses, followed by peaks in Plantago maritima and Triglochin maritimum. Grass pollen predominates in July, followed by high numbers of locally derived chenopod pollen, produced by Salicornia and Atriplex triangularis.

The silty sands of this site contain moderately high numbers of pollen of Chenopodiaceae (30%), Gramineae (22%) and Alnus (21%) (Fig. 21b). In contrast, the levels of Pinus pollen and Triglochin pollen are low. Many of the grains are badly corroded, reflecting the considerable biologic activity in the sediments. Chitinous tests of microforaminifera and hystrichospheres are abundant, and there is a lot of finely dispersed black detritus.

2. Coastal grassland (Site F).

At this locality, about 70 m north of site E and behind a ridge of

drifted logs colonized by Elymus mollis, grasses predominate (Fig. 22c) with Aster subspicatus and Achillea millefolium as the other major components of the vegetation.

The pollen rain diagram (Fig. 22a) resembles that from the chenopod salt marsh in the spring, with regional arboreal species well represented. Peaks in Rumex and Triglochin occur immediately afterward. Throughout the rest of the season, grass pollen comprises virtually all of the pollen rain. At this site, chenopod pollen never reaches as high values as at site E, suggesting that the absolute number of grains to reach site F is lower. At the end of the season, pollen produced by locally growing Compositae is mixed with that of the grasses.

Pollen analysis of the sandy fibrous soil reveals that the pollen of the Chenopodiaceae is the most common. Grass pollen occurs in surprisingly low quantities in spite of its high level in the pollen-rain (Fig. 22b). Many of the grains are folded and corroded. As in bog sediments, grass pollen is apparently selectively destroyed because of its thin exine. The percentage of Compositae pollen reflects the proportion of this group in the vegetation (Fig. 22c). The soil contains numerous amorphous, organic aggregates attesting to the possible loss of pollen through decomposition.

Fluvial Environments - Surface Samples:

1. River marshes (Sites L-1, 2, & 3).
2. River swamps (Sites L-4, 5).
3. Delta-front marshes (Sites DF-1, 2, 3 & 4).
4. Delta-front short core (Site DF-5).

Surface samples were analyzed palynologically from selected environments along channels and at the mouth of the Fraser River (Fig. 10) to

obtain the pollen and spore "fingerprints" characteristic of the sediments in these sites. In addition, a short core was taken to determine whether the horizontal zonation of plant assemblages on the emergent delta-front was recorded as a successional sequence in sediments just outside the dike.

1. River marshes (Sites L-1, 2, & 3).

Three samples of organic silts were obtained from a marsh between the tree-covered banks (Alnus rubra, Populus balsamifera subsp. trichocarpa, Salix spp., Picea sitchensis) and the active river channel. Here the vegetation consists of emergent aquatics, with Menyanthes trifoliata, Lysichitum americanum, Carex sp. and Gramineae growing nearest to the bank. Dense stands of Scirpus sp., Equisetum sp. and sometimes Typha latifolia are located at the edge of the water, and Alisma plantago-aquatica and Sagittaria latifolia grow among the stems of these plants.

In the AP (Fig. 23 a, b, c), Pinus and Alnus predominate, with smaller but significant amounts of Tsuga heterophylla and Picea also present. Many of the arboreal grains are considerably corroded. Taken together, these features indicate a river source for at least part of the arboreal component. The high levels of Pinus must be attributed to river transport, as the nearest source of pine is Burns Bog 5 km away. Cyperaceae pollen characterizes the NAP, probably originating from two sources; river transport and local vegetation. Undamaged grains are fairly abundant and it seems that these were produced locally. The NAP appears to reflect vegetation variation from site to site as demonstrated in Fig. 23a from site L-1, near which Lysichitum and Gramineae grow, and in Fig. 23c from site L-3 surrounded partly by Equisetum sp. In all cases the proportion of the pollen and spore

types of these species is low in comparison to their major role in the local vegetation. Particularly interesting is the absence of Menyanthes pollen at L-1 (Fig. 23a) where the plant grows well and many seed pods are produced. Typha, occupying major areas of the local vegetation, is also poorly represented, as are Sagittaria and Alisma. It was observed that very few flowers were formed by these last two genera. Equisetum in these habitats, produces limited numbers of spores in small strobili. Fungal spores are not abundant; only a few cf. Curvularia, cf. Periconia and type 1 were found.

2. River swamps (Sites L-4, & 5).

Samples from site L-4 and L-5 were taken from a quiet backswamp, behind partially natural levees. The same tree species as near sites L-1 to L-3 surround the area and Salix spp., Rubus spectabilis and Cornus sericea appear to be advancing into the swamp. The surface is infrequently inundated during periods of high water. The vegetation of L-4 and L-5 is very similar to that of the river marshes, with Lysichitum americanum, Typha latifolia, Equisetum sp. and Scirpus sp. dominating.

Similarities also occur in the pollen spectra of the river marshes (Fig. 23a, b, c) and river swamp sites (Fig. 24a, b), with Pinus and Alnus predominating. Tsuga is also present, whereas Picea is absent. The local colonies of Typha, Equisetum and Lysichitum are reflected in the NAP fraction. The discovery of Sphagnum spores at both L-4 and L-5 seems unusual as no Sphagnum grows anywhere in the vicinity. The source of these spores appears to be a ditch some 200 m east of the sites which drains Burns Bog, about 1-2 km to the south. It also seems likely that ditch output also provides some of the pine pollen.

Fungal microfossils are also preserved in these backswamp sediments, including cf. Periconia, Tilletia and cf. Dactylaria.

3, Delta-front marshes (Sites DF-1, 2, 3, 4).

Surface samples were analyzed from each of three recognizable plant assemblages (zones) seaward of the dike on the northern end of Lulu Island (Fig. 10). Conditions here are brackish from mixing of fresh water from the Middle Arm of the Fraser River with salt water from the Strait of Georgia.

The emergent plant communities of the delta-front have been described by Forbes (1972). Scirpus americanus and Scirpus paludosus form the first emergent plant assemblage (Fig. 25). A surface sample was taken from each of two sites; one dominated by S. americanus (DF-1), the other dominated by S. paludosus (DF-2). Silts were sampled in the Typha latifolia zone (DF-3), bordering the Scirpus spp. zone on the shoreward side, and also from the Carex lyngbeyi-Potentilla pacifica assemblage (two samples) (site DF-4) between the Typha zone and the dike. This last assemblage, although dominated by sedges, also contains considerable numbers of Oenanthe sarmentosa.

The pollen spectra for DF-1, 2, 3, and 4 (Fig. 26a, b, c, respectively) all show high percentages of Pinus and Alnus and hence are comparable with sites along the river. In the Scirpus spp. and Carex-Potentilla zones, Cyperaceae pollen ranges from 40-50%. Potentilla pollen, although present in small quantities (2%) (Fig. 26c), is probably diagnostic of the Carex-Potentilla zone. In the Typha latifolia stand, Typha tetrads reach about 30%, whereas Cyperaceae frequencies are reduced. Gramineae pollen is significantly represented in all diagrams, reflecting the agricultural fields on shore. The percentages of cf. Athyrium fern spores is surprising as no

ferns grow in these marshes. However, Athyrium filix-femina has been observed growing sporadically in semi-open, swampy habitats along the river. This fern produces tremendous quantities of spores in sporangia that readily break away from their attachment in the sorus. Both sporangia and spores may be subsequently floated down the river and deposited in the silts of the delta-front. Reworked Tertiary pollen (recognized on the basis of amber colour) seems similarly to be washed down the river and deposited litorally, as numerous reworked grains are recovered from DF-1 and 2. Fluvial transport of palynomorphs with subsequent littoral deposition has been noted for other large rivers (Muller, 1959).

A host of non-vascular plant palynomorphs characterizes delta-front sediments. Two types, cf. Periconia and Type 1 occur in great numbers in these particular habitats. Large, clear, thick-walled palynomorphs (fungal oogonia) also appear to be representative of these sediments. Other types encountered include Diporisporites Hammen emend Elsik (Elsik, 1968) and chitinous tests of foraminifera. There is a high concentration of organic fragments and fine black detritus.

4. Delta-front short core (Site DF-5).

A short core (1 m x .05 m diameter) was obtained by driving a stainless steel tube into the organic silts just off the dike in the Carex-Potentilla community. Ninety centimeters were recovered, divided into 15 cm lengths, and analyzed for pollen. The pollen diagram of the major species (Fig. 27) reveals two stages. The bottom half with high percentages of Cyperaceae pollen represents the Scirpus spp. zone. From about the .65 m level, the frequency of Typha latifolia increases markedly, accompanied by a decrease in Cyperaceae pollen. This change represents the development of the Typha

latifolia community shoreward of the Scirpus spp. zone. The shift to the present Carex-Potentilla assemblage has occurred very recently, as there is no indication of this (such as decreasing Typha) in the upper levels of the core. Grass pollen is well preserved, in marked contrast to both bog and coastal meadow deposits. One possible explanation is that the relatively thin walled grass pollen preserves best when deposited in an environment that is often submerged, whereas grass pollen deposited on surfaces that dry out is rapidly destroyed, possibly by oxidation and microorganism attack.

Summary and Conclusions

The results of this study of pollen rain, of pollen spectra of surface samples, and of the relationship of these to vegetation, show that vegetation types in the study area can be characterized and differentiated on the basis of palynomorph assemblages including microfossils other than pollen and spores. However as Cohen (1973) observed, interpretation of plant assemblage composition can not be made on the basis of abundance of pollen types.

Currently forming bog deposits contain high concentrations of Pinus, Alnus, and Ericaceae and sometimes of Sphagnum spores. Wet and dry heath-land communities can be differentiated on the basis of tetrad diameter distribution in the ericad spectrum of the surface sediments. Areas of birch, Spiraea or Pteridium contain relatively high percentages of these species in the surface deposits. Salt marsh and coastal grassland sediments are characterized by high concentrations of chenopod and grass pollen. Fluvial sediments of marshes and swamps contain high percentages of Pinus along with considerable Picea, Tsuga and Alnus. Cyperaceae grains also

occur abundantly but other locally dominant types such as Menyanthes and Equisetum sp. are underrepresented. Sediments of the intertidal zone of the delta-front similarly contain abundant quantities of Pinus, Picea, Tsuga and Alnus pollen. Cyperaceae pollen levels are high in the silts of the Scirpus spp.-dominated zone and the Carex lyngbeyi-Potentilla pacifica zone. The silts below Typha stands contain abundant Typha tetrads.

The palynomorph assemblages of the different wetland environments examined provide "fingerprints" for the recognition of these environments in sediments obtained from cores.

Figures 11-27, Table 3.

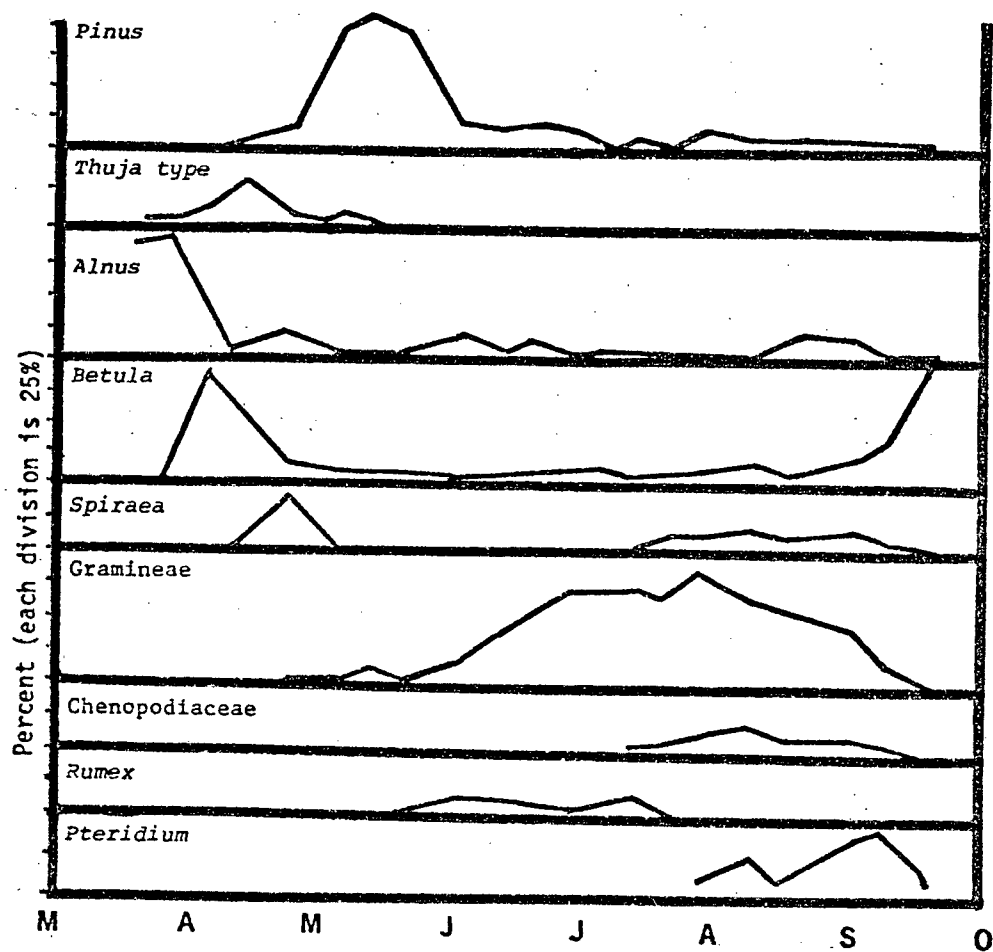
The following pages contain the figures referred to in Ch. 4. The diagrams for each site are grouped under one figure number which is subdivided as follows:

- a) pollen rain,
- b) surface pollen spectrum,
- c) species cover (vegetation).

Fig. 25 (p. 92) depicts the vegetation zones of the Lulu Island fore-shore. Fig. 27 (p. 94) is the pollen diagram for the short core taken at site DF-5. Table 3 (p. 95) summarizes the distribution of non-vascular plant palynomorphs from wetland sites investigated by pollen analysis of surface samples.

Figure 11: Diagrams for site A, open *Betula occidentalis* woodland with *Pteridium aquilinum* understorey;

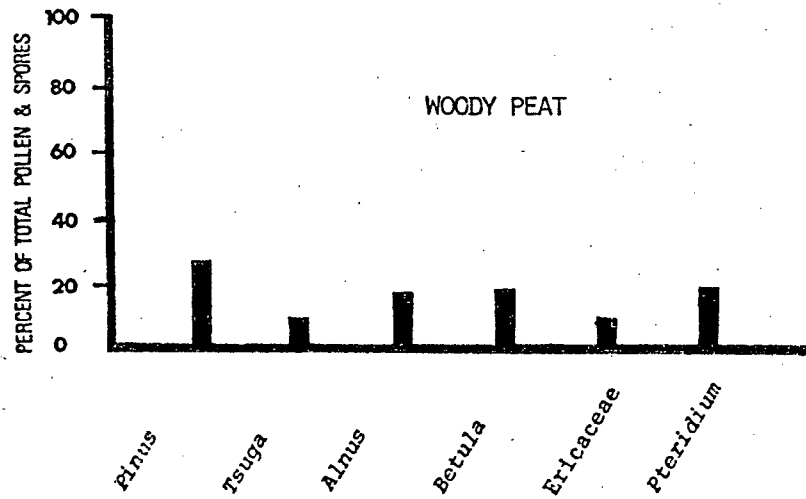
11a) pollen rain diagram



Other types; *Tsuga*, *Picea*, *Abies*, *Pseudotsuga*, *Acer macrophyllum*, *Ericaceae*, *Myrica*, *Cyperaceae*, *Plantago*, *Liliaceae*, *Compositae*, *Typha*, *Leguminosae*, *Monolete Polypodiaceae*, *Sphagnum*.

Figure 11b,c: Diagrams for site A continued;

11b) surface pollen spectrum



Other types; *Picea*(1%), *Abies*(.5%), *Pseudotsuga*(3%), *Spiraea*(1%), *Compositae*(1%), *Gramineae*(2%), average of 3 samples.

11c) species cover

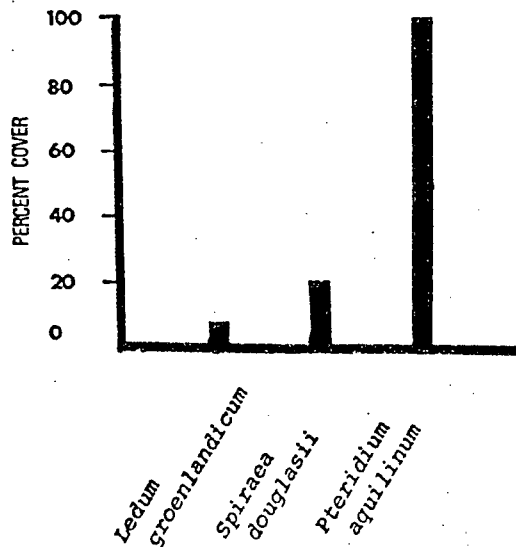
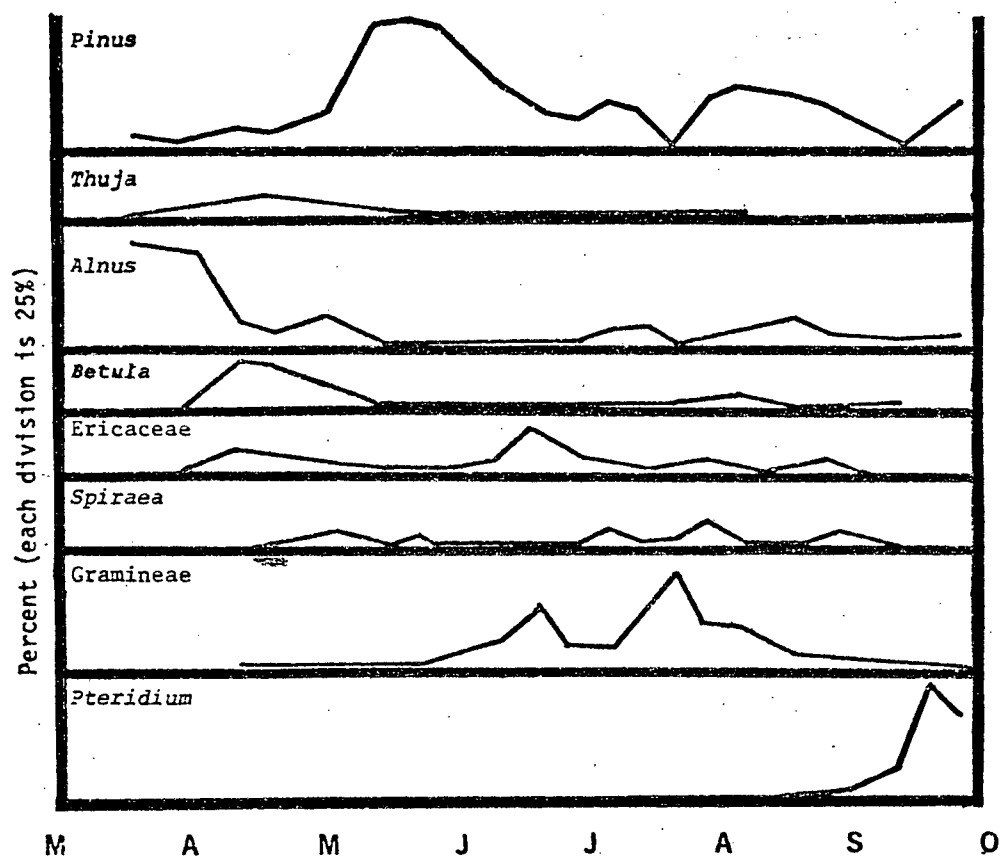


Figure 12: Diagrams for site B, Ledum groenlandicum heathland in Pinus contorta woodland;

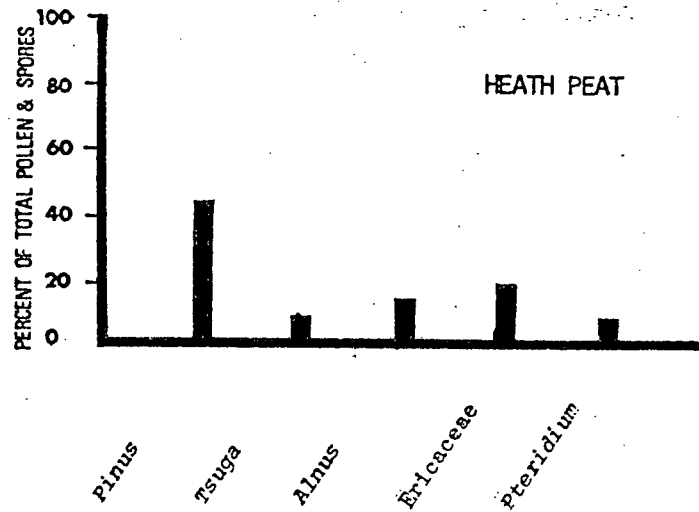
12a) pollen rain diagram



Other types; *Tsuga*, *Picea*, *Abies*, *Pseudotsuga*, *Ilex*, *Salix*, *Acer macrophyllum*, *Cyperaceae*, *Chenopodiaceae*, *Plantago*, *Rumex*, *Compositae*, *Umbelliferae*, *Monolete Polypodiaceae*, *Sphagnum*.

Figure 12b,c: Diagrams for site B continued;

12b) surface pollen spectrum



Other types; *Abies* (1%), *Picea* (2%), *Pseudotsuga* (1%),
Thuja (1%), *Betula* (2%), *Gramineae* (2%), *Cyperaceae* (1%),
Sphagnum (1%), average of 3 samples.

12c) species cover

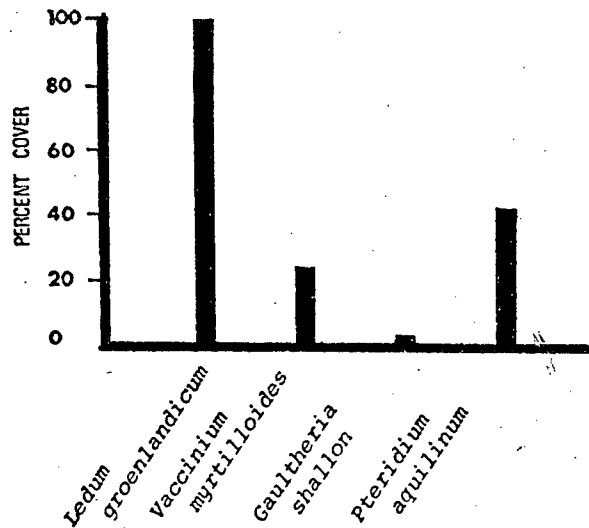
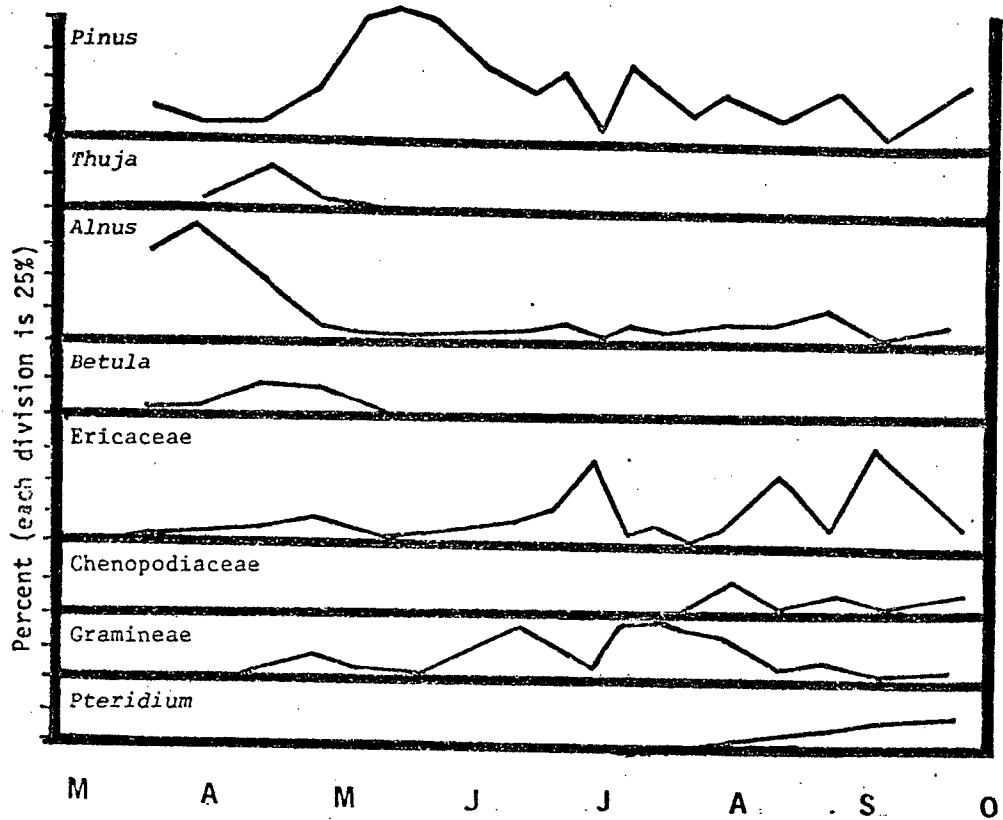


Figure 13: Diagrams for site C, Ledum groenlandicum heathland in Pinus contorta woodland;

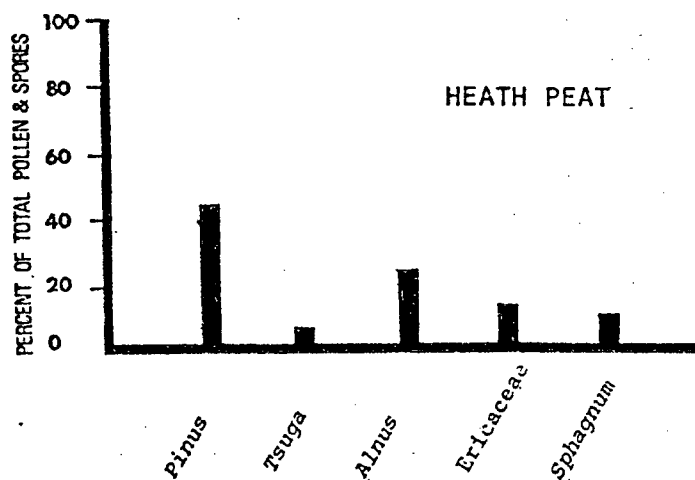
13a) pollen rain diagram



Other types; *Tsuga*, *Picea*, *Abies*, *Pseudotsuga*, *Acer macrophyllum*, *Salix*, *Spiraea*, *Cyperaceae*, *Plantago*, *Rumex*, *Typha*, *Leguminosae*, *Umbelliferae*.

Figure 13 b,c: Diagrams for site C continued;

13b) surface pollen spectrum



Other types; *Abies* (1%), *Picea* (1%), *Pseudotsuga* (1%), cf. *Thuja* (1%), *Betula* (2%), *Umbelliferae* (1%), *Gramineae* (3%), *Chenopodiaceae* (1%), *Compositae* (1%), *Pteridium* (3%), average of 3 samples.

13c) species cover

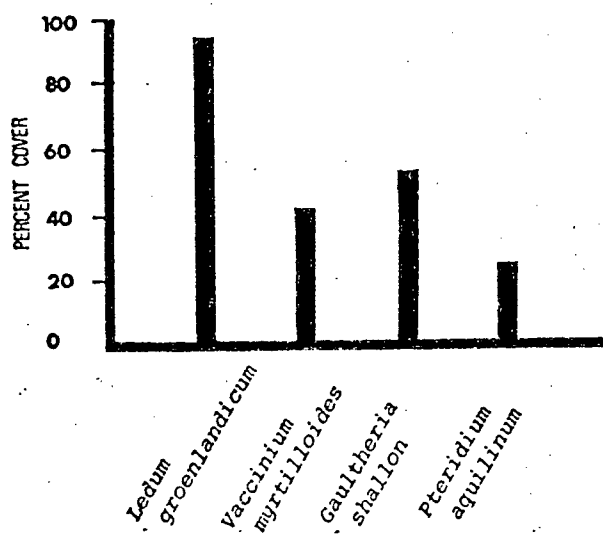
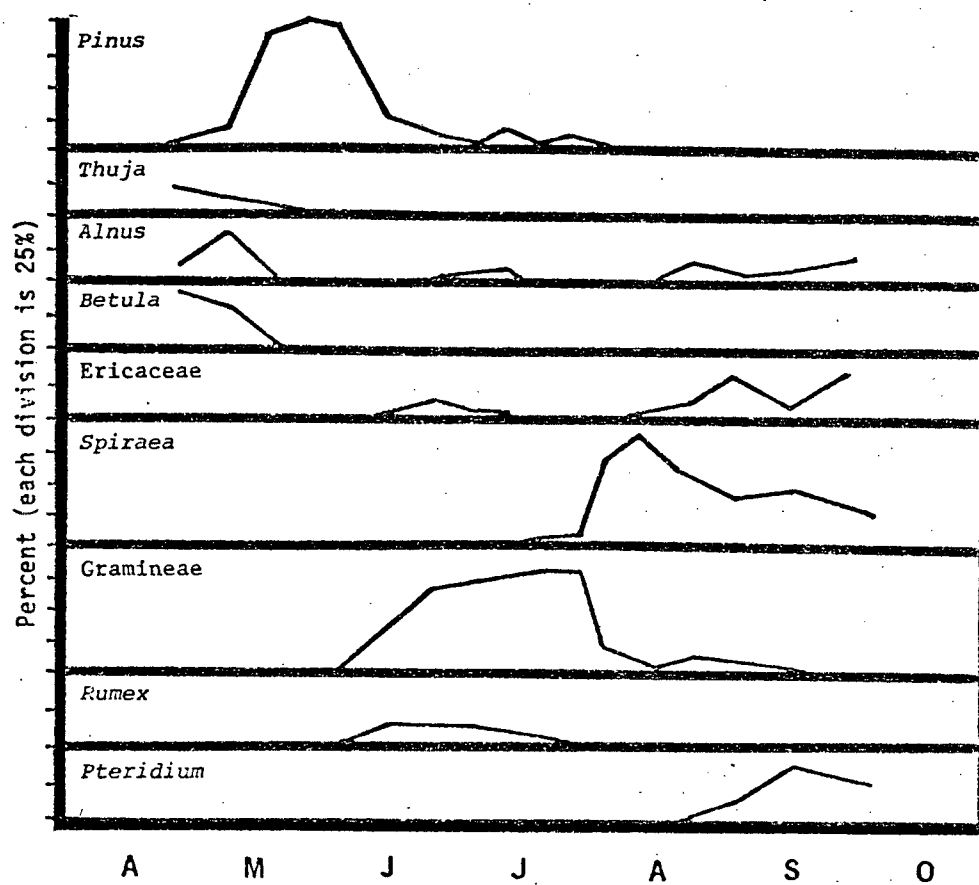


Figure 14: Diagrams for site D, Spiraea douglasii thickets in open Betula occidentalis woodland;

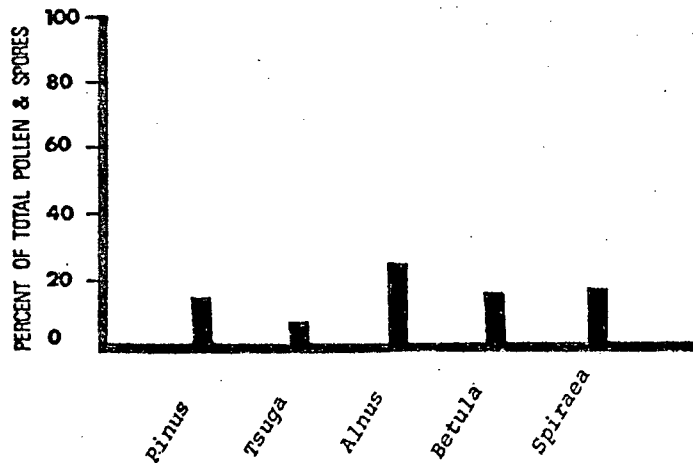
14a) pollen rain diagram



Other types; *Tsuga*, *Picea*, *Abies*, *Pseudotsuga*, *Acer macrophyllum*, *Salix*, *Cyperaceae*, *Chenopodiaceae*, *Plantago*, *Liliaceae*, *Compositae*, *Typha*, *Leguminosae*, *Umbelliferae*, *Monolete Polypodiaceae*.

Figure 14b,c: Diagrams for site D continued;

14b) surface pollen spectrum



Other types; *Abies* (1%), *Picea* (2%), *Pseudotsuga* (1%), cf. *Thuja* (1%), *Acer macrophyllum* (1%), *Ericaceae* (2%), *Gramineae* (4%), *Chenopodiaceae* (1%), *Compositae* (1%), *Typha latifolia* (1%), *Cyperaceae* (2%), *Nuphar* (2%), *Pteridium aquilinum* (4%), *Sphagnum* (2%), average of 3 samples.

14c) species cover

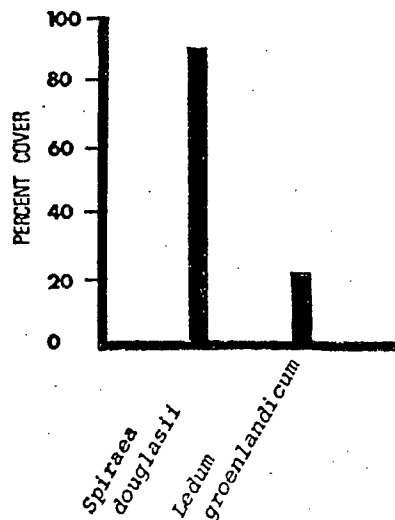
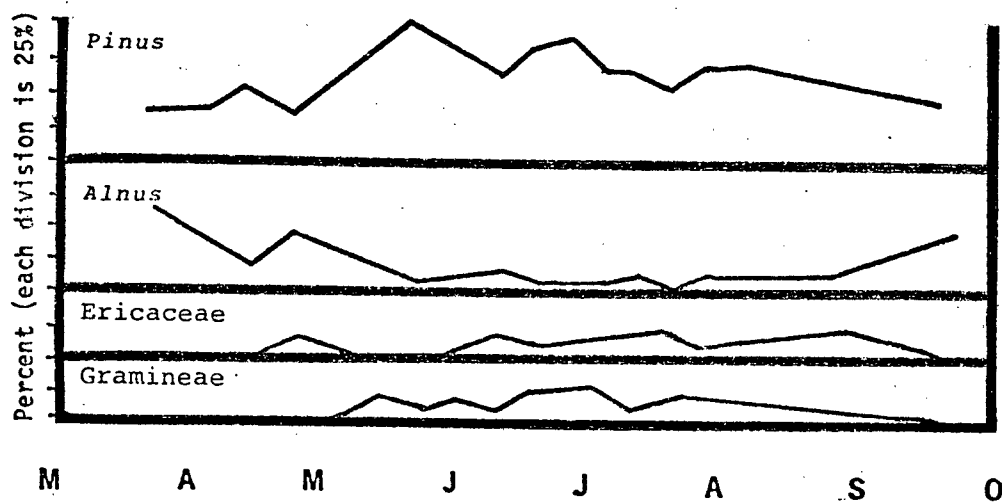


Figure 15: Diagrams for site H, Pinus contorta woodland;

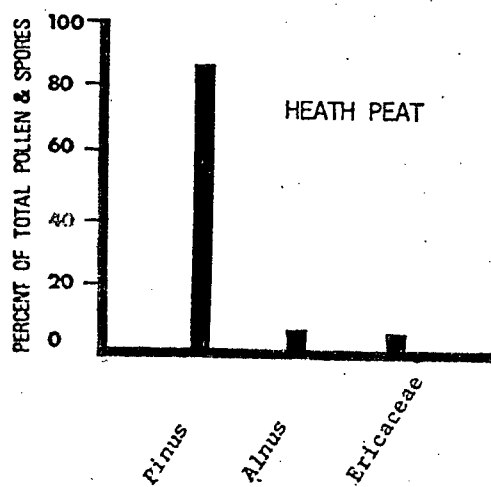
15a) pollen rain diagram



Other types; *Thuja*-type, *Tsuga*, *Abies*, *Pseudotsuga*, *Betula*, *Typha*,
Chenopodiaceae, *Plantago*, *Leguminosae*, *Sphagnum*, *Pteridium*, *Polypodiaceae*.

Figure 15 b,c: Diagrams for site H continued;

15b) surface pollen spectrum



Other types; *Abies* (.5%), *Gramineae* (1%), average of 3 samples.

15c) species cover

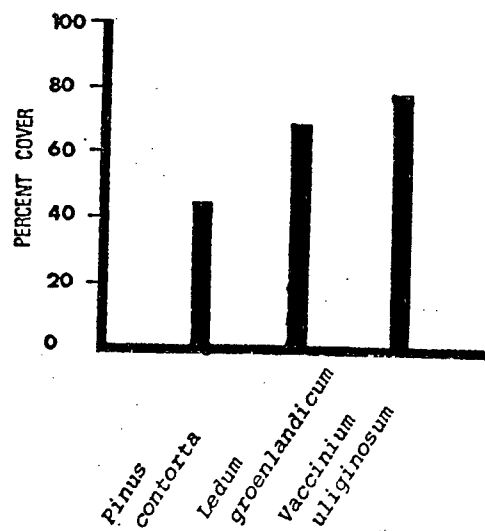
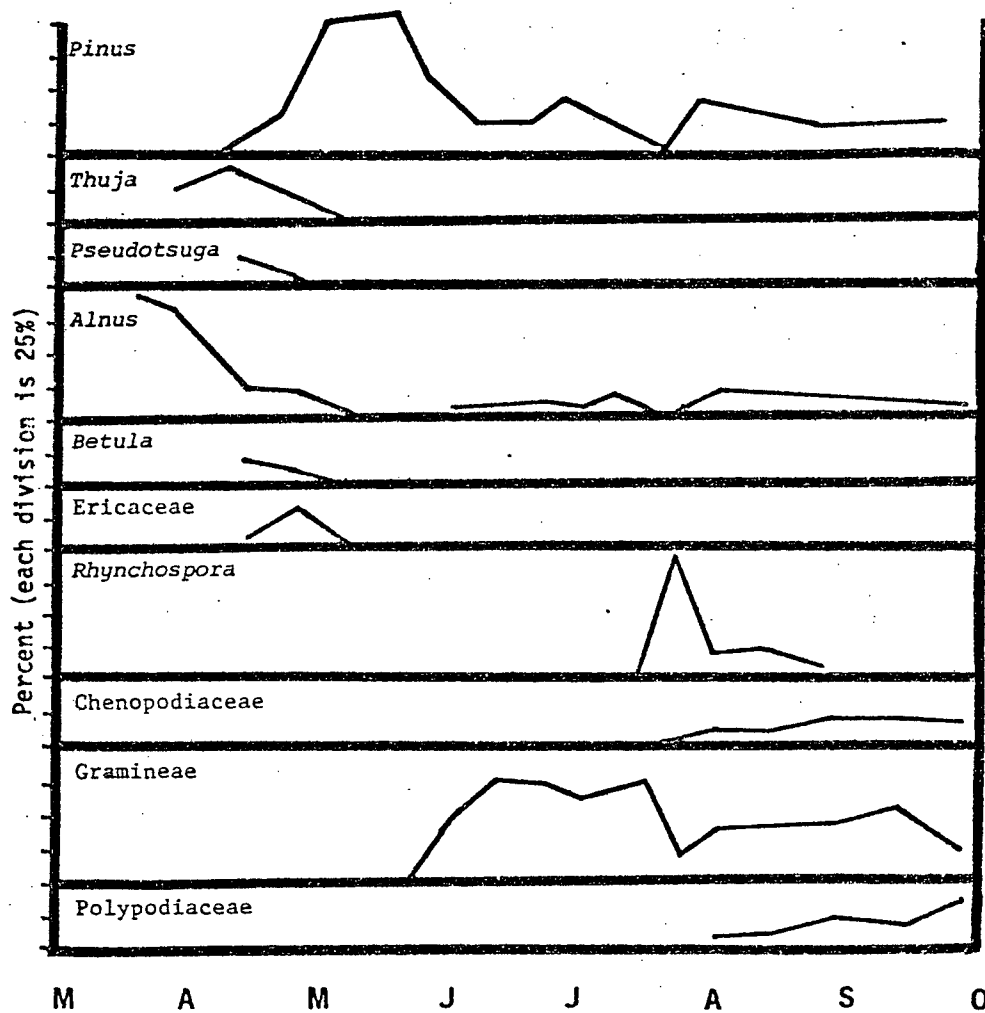


Figure 15: Diagrams for site I, Sphagnum heathland;

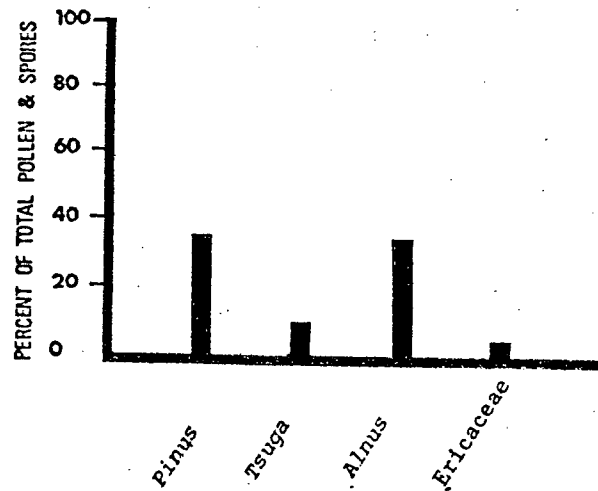
16a) pollen rain diagram



Other types; *Tsuga*, *Picea*, *Abies*, *Acer macrophyllum*, *Spiraea*, *Cyperaceae*, *Plantago*, *Rumex*, *Compositae*, *Typha*, *Leguminosae*, *Liliaceae*, *Umbelliferae*, *Sphagnum*.

Figure 16 b,c: Diagrams for site I continued;

16b) surface pollen spectrum



Other types; *Abies*(1%), *Picea*(1%), *Pseudotsuga*(3%), cf. *Thuja*(1%), *Betula*(1%), *Spiraea*(.5%), *Rubus chamaemorus*(.5%), *Chenopodiaceae*(1%), *Cyperaceae*(1%), *Typha*(1%), *Sphagnum*(3%), average of 3 samples.

16c) species cover

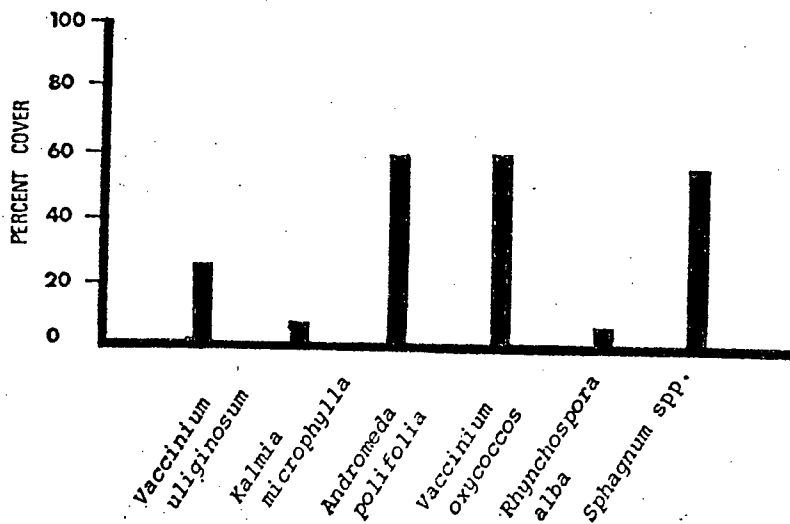
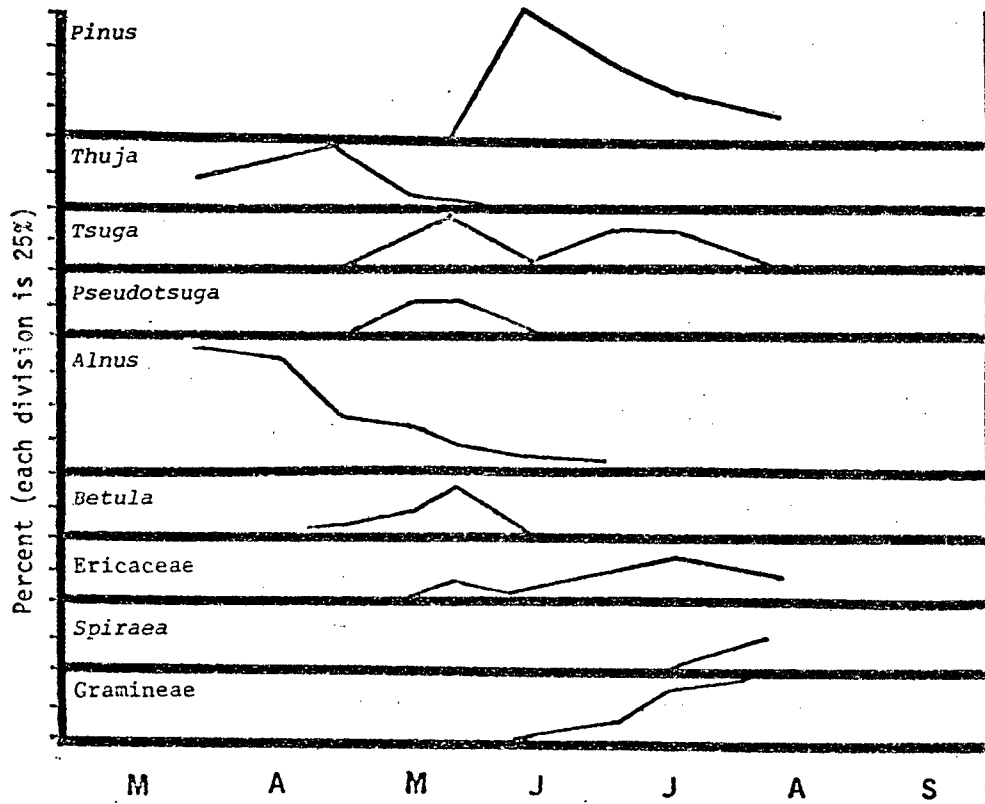
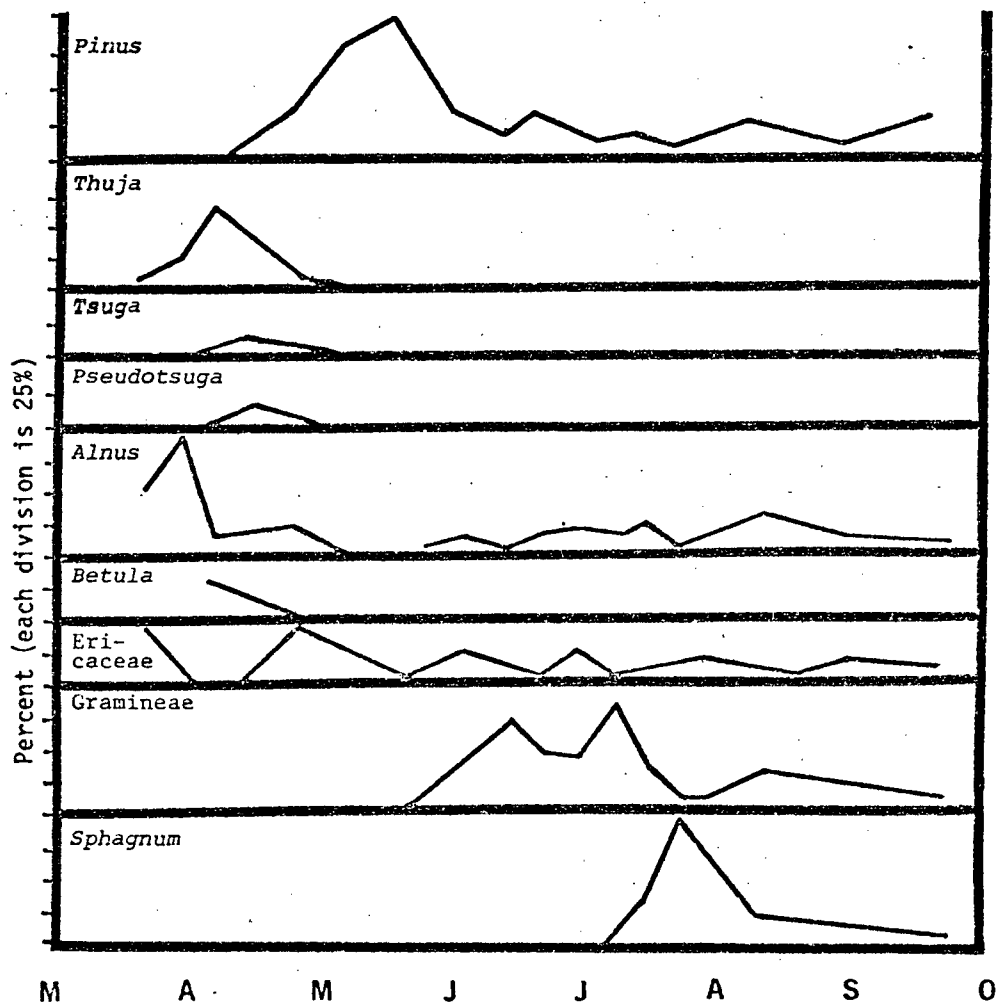


Figure 17: Pollen rain diagram for site R, Sphagnum heathland.

Other types; *Picea*, *Abies*, *Acer macrophyllum*, *Cyperaceae*, *Plantago*, *Rumex*, *Typha*, *Compositae*, *Leguminosae*, *Polypodiaceae*, *Sphagnum*.

Figure 18: Diagrams for site G, Sphagnum heathland clearing in
in Pinus contorta woodland.

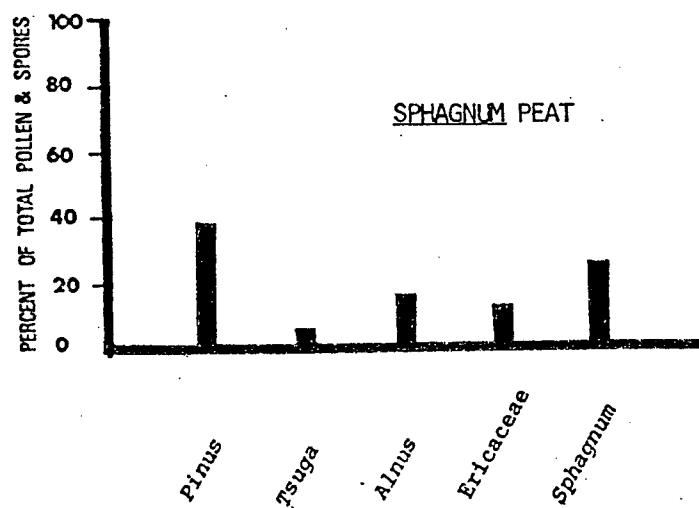
18a) pollen rain diagram



Other types; *Picea*, *Abies*, *Acer macrophyllum*, *Salix*, *Myrica*, *Spiraea*,
Typha, *Rhynchospora*, *Cyperaceae*, *Chenopodiaceae*, *Compositae*, *Plantago*,
Polygonum, *Rumex*, *Nuphar*, *Leguminosae*, *Pteridium*, *Polypodiaceae*.

Figure 18 b,c: Diagrams for site G continued;

18b) surface pollen spectrum



Other types; *Abies* (1%), *Picea* (.5%), *Pseudotsuga* (15), cf. *Thuja* (1%), *Rubus chamaemorus* (.5%), Gramineae (1%), average of 3 samples.

18c) species cover

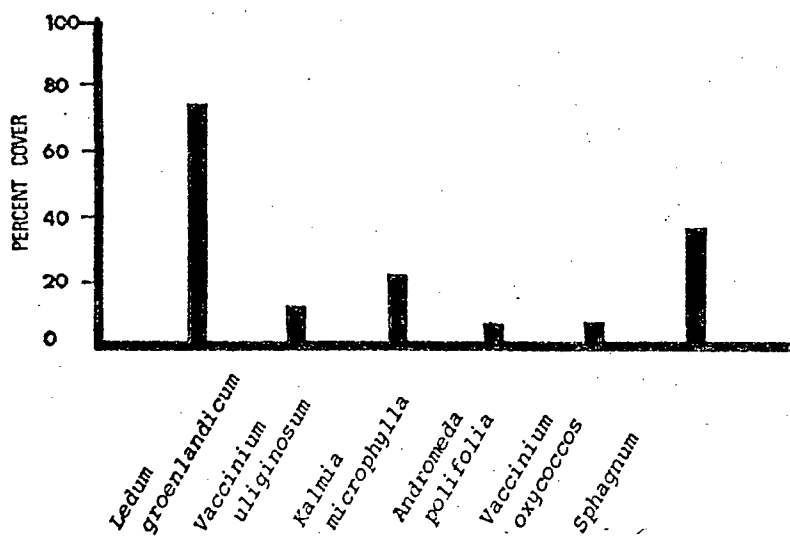
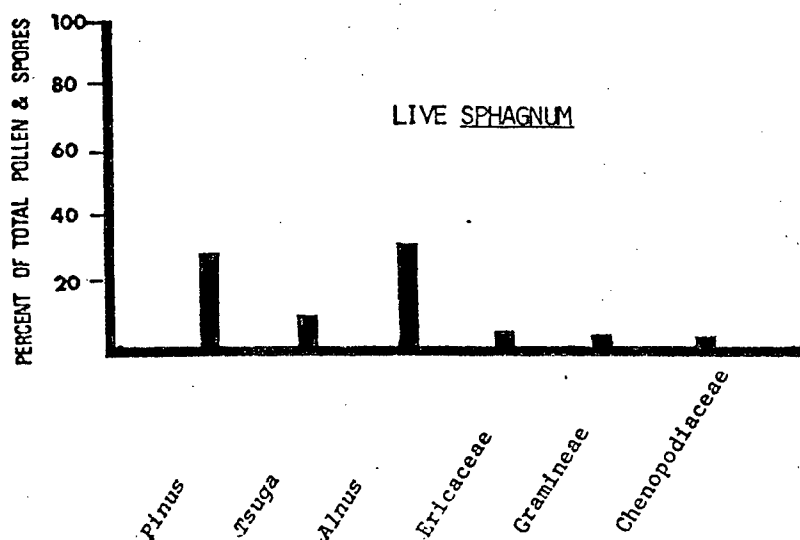


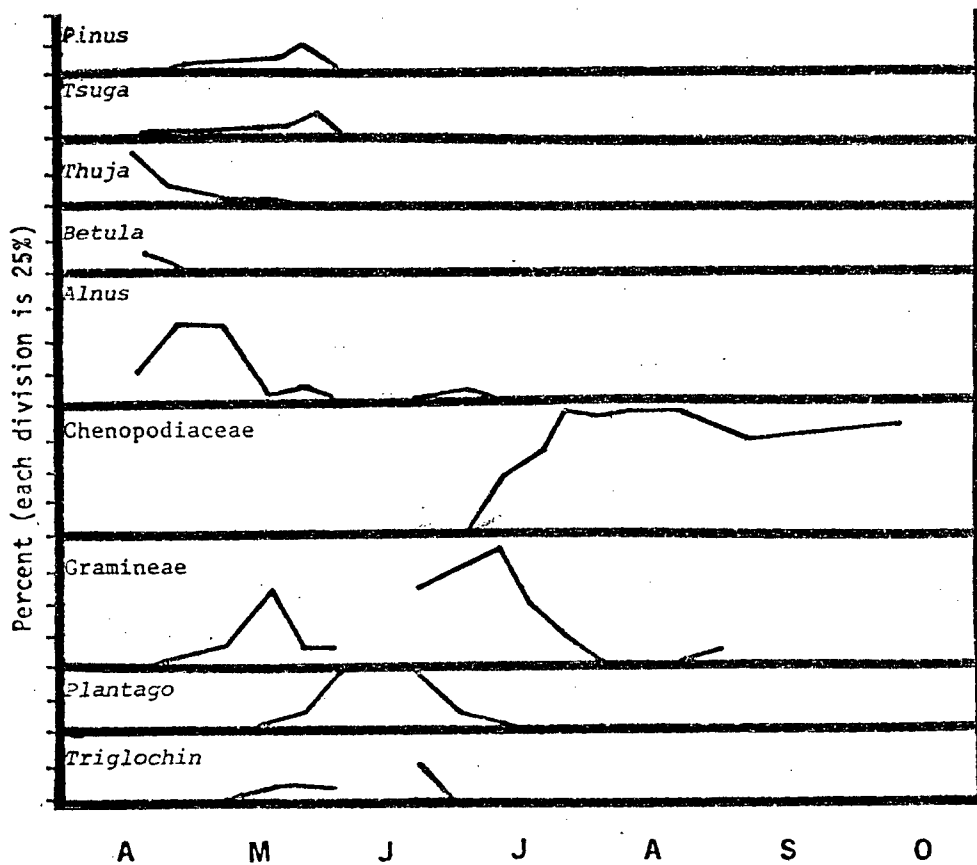
Figure 19: Surface pollen spectrum, site NP, Nuphar pond, in Sphagnum heathland.



Other types; *Abies*(1%), *Picea*(.5%), *Pseudotsuga*(1%), cf. *Thuja* (2%), *Betula*(2%), *Myrica*(1%), *Plantago*(.5%), *Nuphar*(2%), *Sphagnum*(.5%), average of 2 samples.

Figure 21: Diagrams for site E, Chenopodiaceae salt marsh;

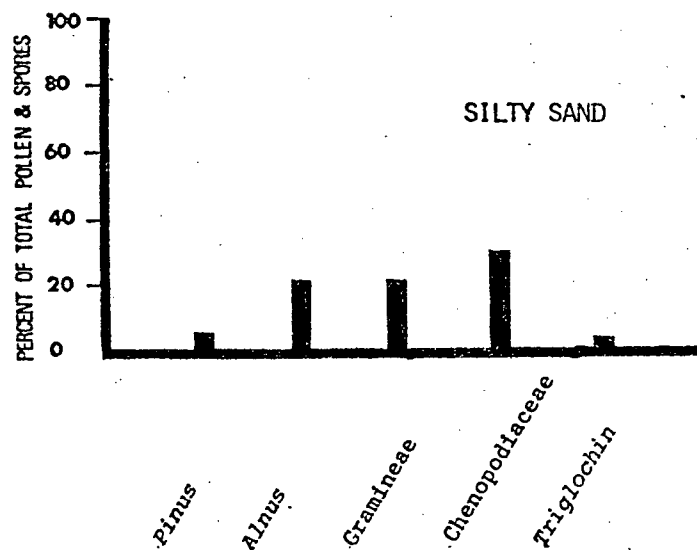
21a) pollen rain diagram



Other types; *Pseudotsuga*, *Acer macrophyllum*, *Salix*, *Rumex*, *Spergularia*, *Cuscuta*, *Juncus*-type, *Compositae*, *Polypodiaceae*.

Figure 21b,c: Diagrams for site E continued;

21b) surface pollen spectrum



Other types; *Abies* (.5%), *Picea* (2%), *Tsuga* (2%), *Pseudo-tsuga* (2%), cf. *Thuja* (1%), *Plantago* (2%), Compositae (2%), Cyperaceae (1%), average of 3 samples.

21c) species cover

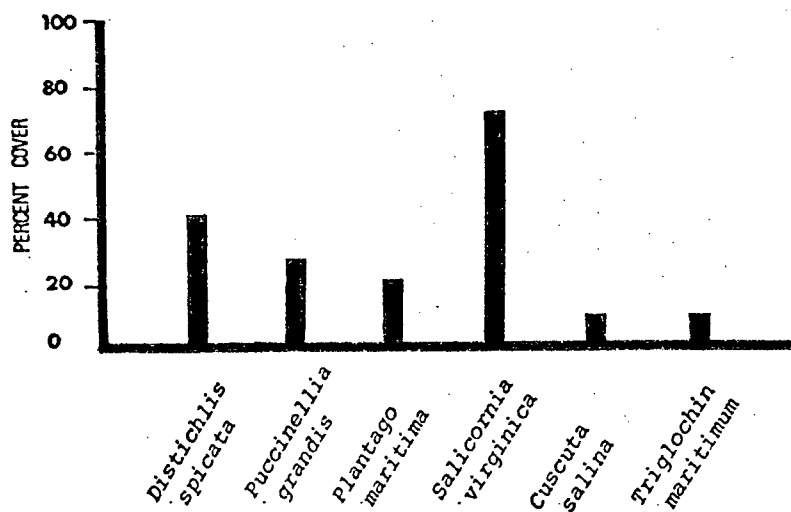
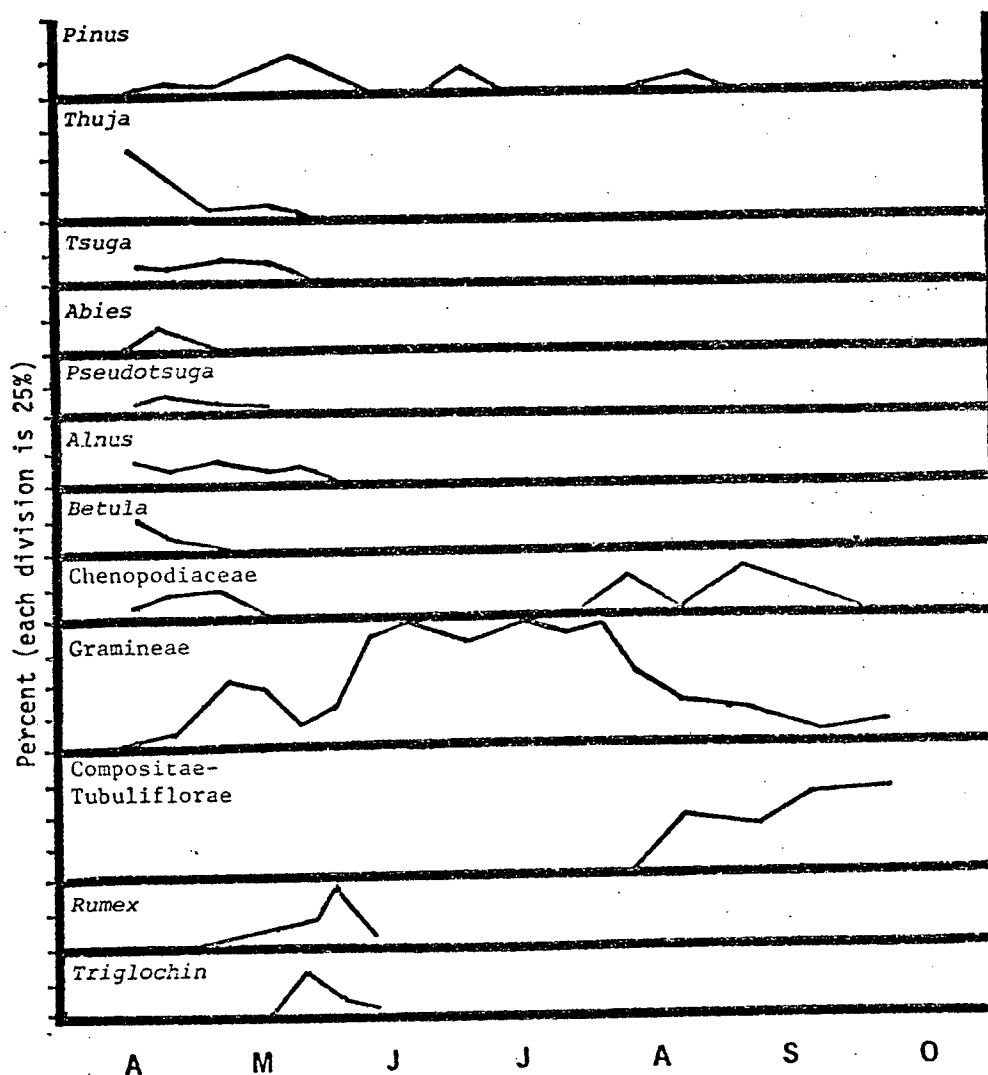


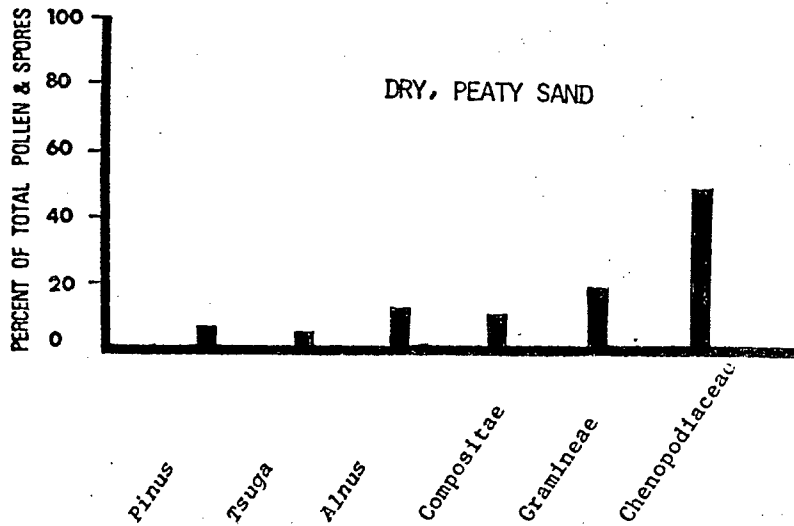
Figure 22: Diagrams for site F, coastal grassland;

22a) pollen rain diagram



Other types; *Acer macrophyllum*, *Salix*, *Cuscuta*, *Plantago*, *Galium*, *Typha*, *Cyperaceae*, *Umbelliferae*, *Polypodiaceae*.

Figure 22 b.c: Diagrams for site F continued;
22b) surface pollen spectrum



Other types; *Picea*(.5%), *Tsuga*(2%), average of 3 samples.

22c) species cover

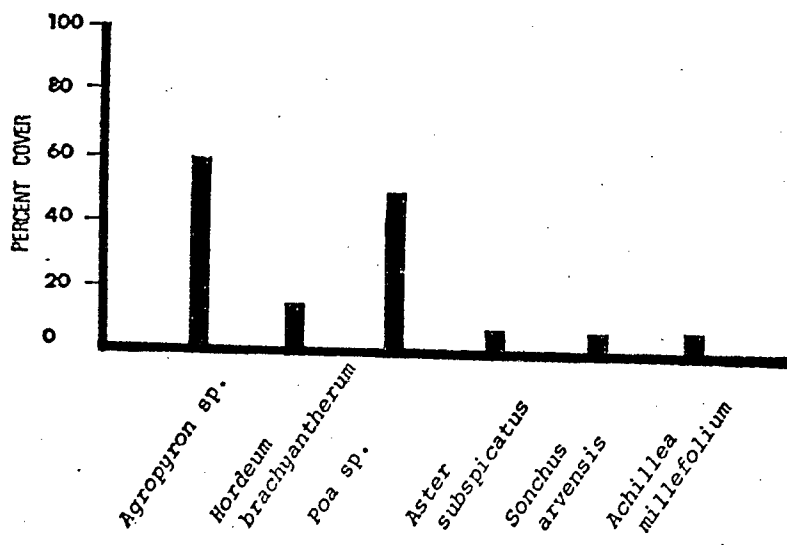
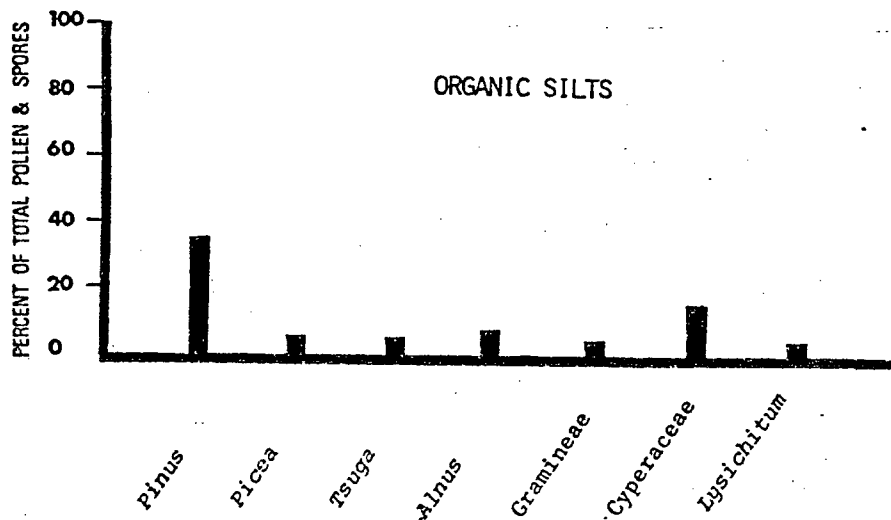
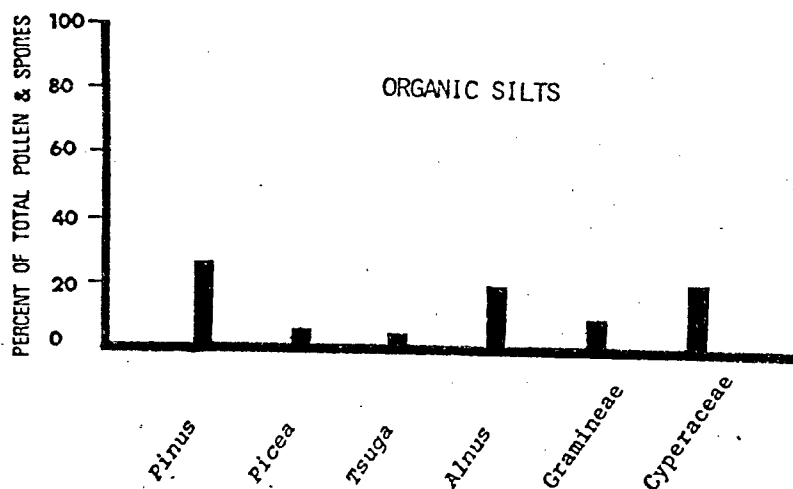


Figure 23: Surface pollen spectra of river marsh sites;

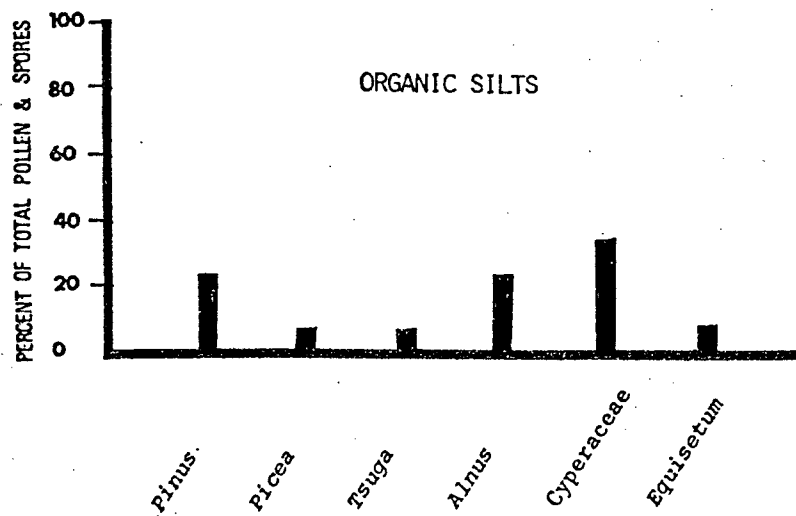
23a). Site L-1, river marsh, Menyanthes-Lysichitum-Gramineae

Other types; *Pseudotsuga* (.5%), *Betula* (.5%), *Ericaceae* (1%), *Typha* (3%), *Equisetum* (3.5%), Monolete ferns (3.5%), *Sphagnum* (2%).

23b) Site L-2, river marsh, Equisetum-Scirpus-Sagittaria-Alisma

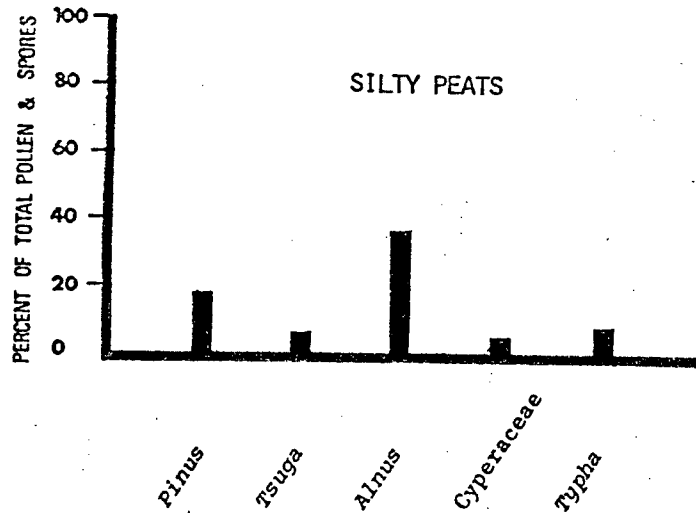
Other types; *Abies* (.5%), *Pseudotsuga* (1%), *cf. Thuja* (2%), *Betula* (1%), *Salix* (1%), *Ericaceae* (.5%), *Chenopodiaceae* (2%), *Typha* (1.5%), *Alisma* (.5%), *Equisetum* (3.5%), Monolete ferns (4%), *Sphagnum* (3.5%).

Figure 23c) Surface pollen spectra of river marsh sites continued;
Site L-3, Scirpus-Sagittaria-Equisetum.

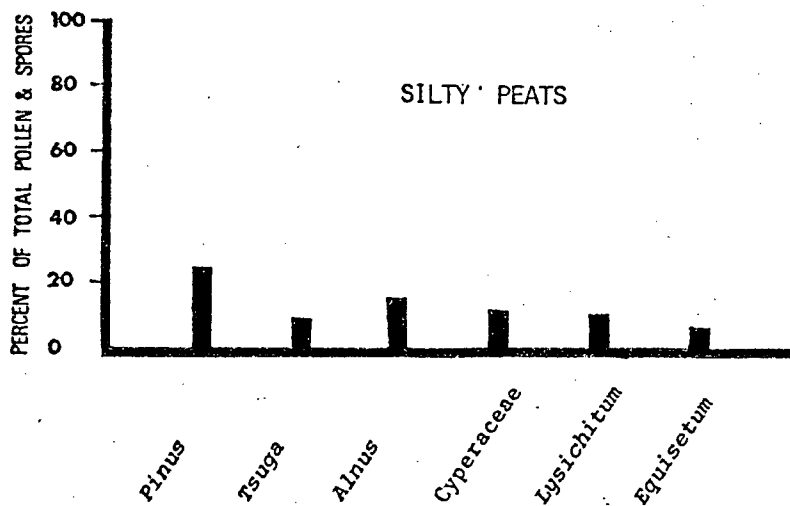


Other types; *Abies* (1%), *Pseudotsuga* (1.5%), *cf. Thuja* (.5%), *Betula* (.5%), *Salix* (.5%), *Myrica* (.5%), *Typha* (2%), Monolete ferns (3%), *Sphagnum* (1%).

Figure 24: Surface pollen spectra of river swamp sites, L-4, L-5;

24a) site L-4, Typha-Equisetum

Other types; *Abies*(1.5%), *Picea*(2%), *Pseudotsuga*(3%), cf. *Thuja* (2%), *Ericaceae*(2.5%), *Arceuthobium*(.5%), *Labiatae*(1%), *Gramineae*(2%), *Chenopodiaceae*(.5%), *Compositae*(.5%), *Lysichitum*(1.5%), *Sagittaria*(1.5%), *Equisetum*(.5%), *Monolete ferns*(1%), *Sphagnum* (8%).

24b) site L-5, Equisetum-Lysichitum-Scirpus

Other types; *Abies*(1.5%), *Picea*(3%), *Pseudotsuga*(1%), *Betula* (.5%), *Ericaceae*(3%), *Gramineae*(1.5%), *Chenopodiaceae*(.5%), *Malvaceae*(.5%), *Typha*(3%), *Sagittaria*(.5%), *Sphagnum*(13%).

FIGURE 25: VEGETATION ZONES OF THE LULU ISLAND FORESHORE*

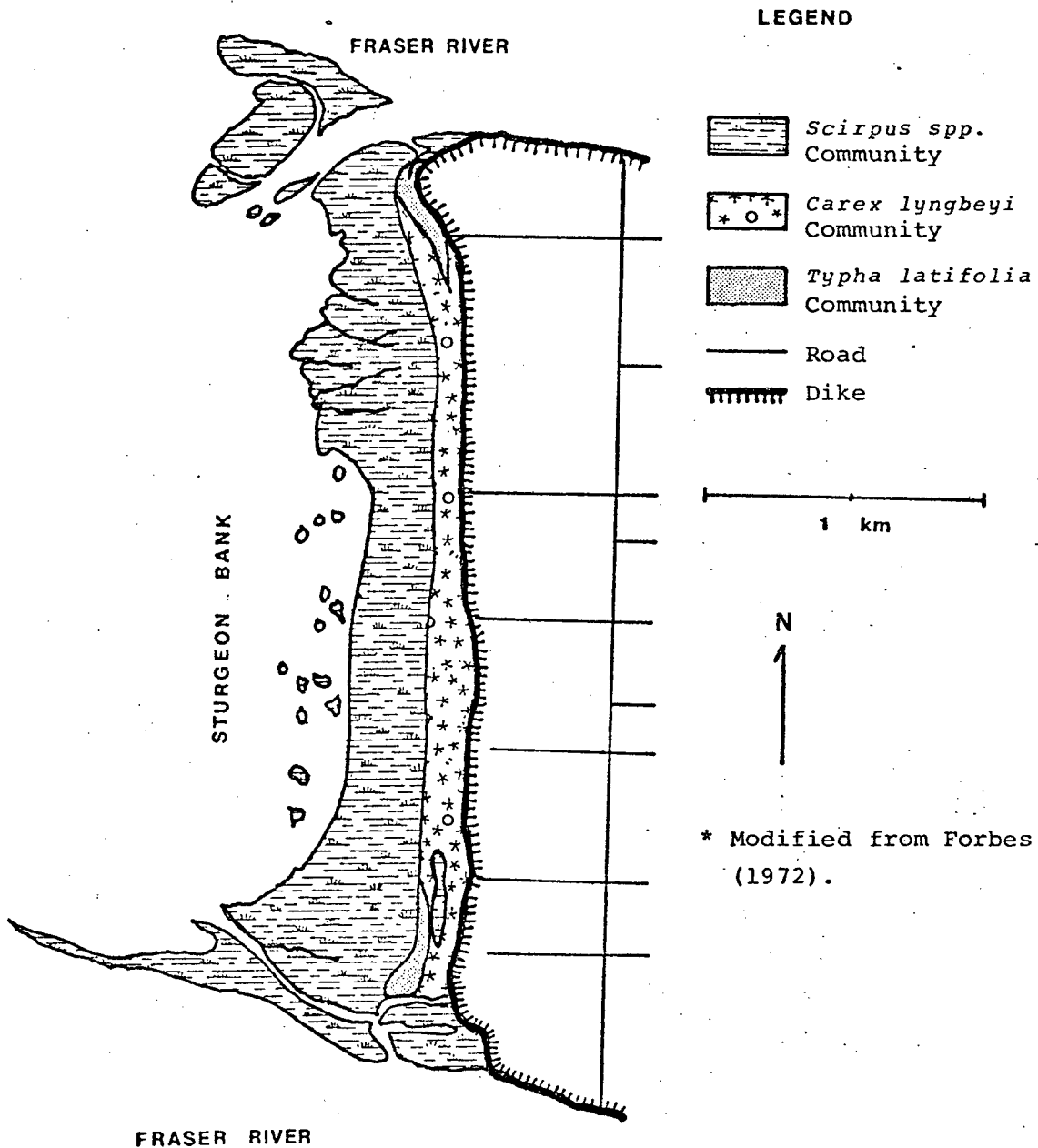


Figure 26: Surface pollen spectra from delta-front marshes, DF 1,2,3 & 4;

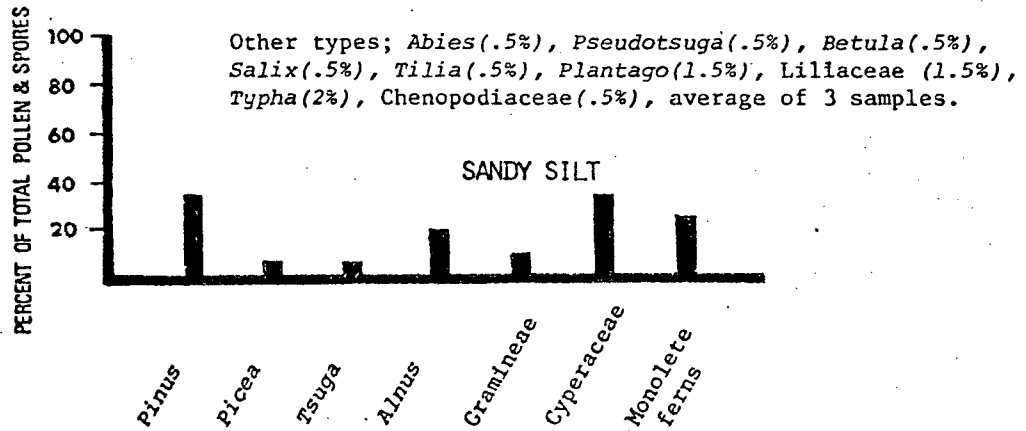
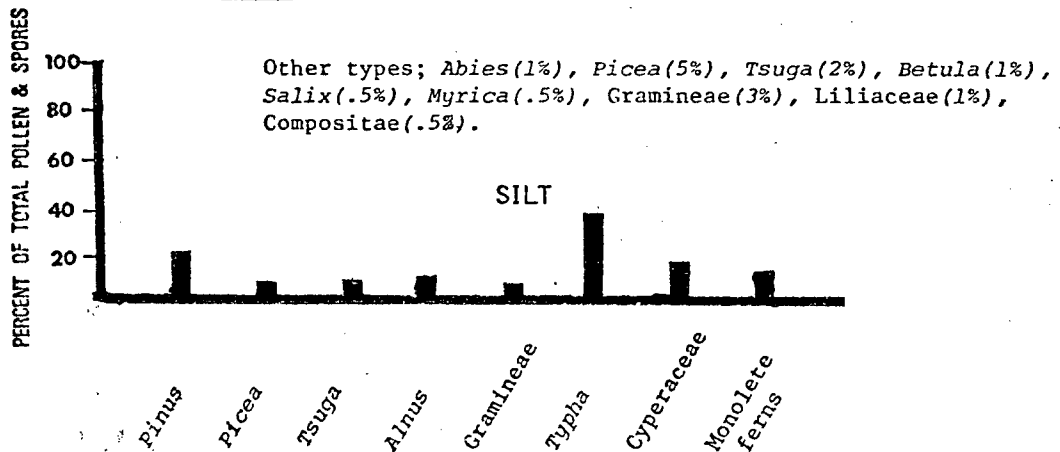
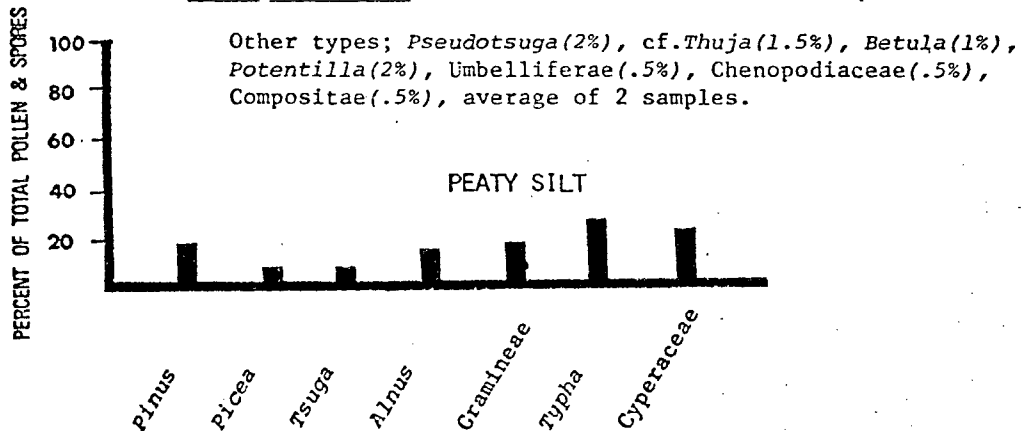
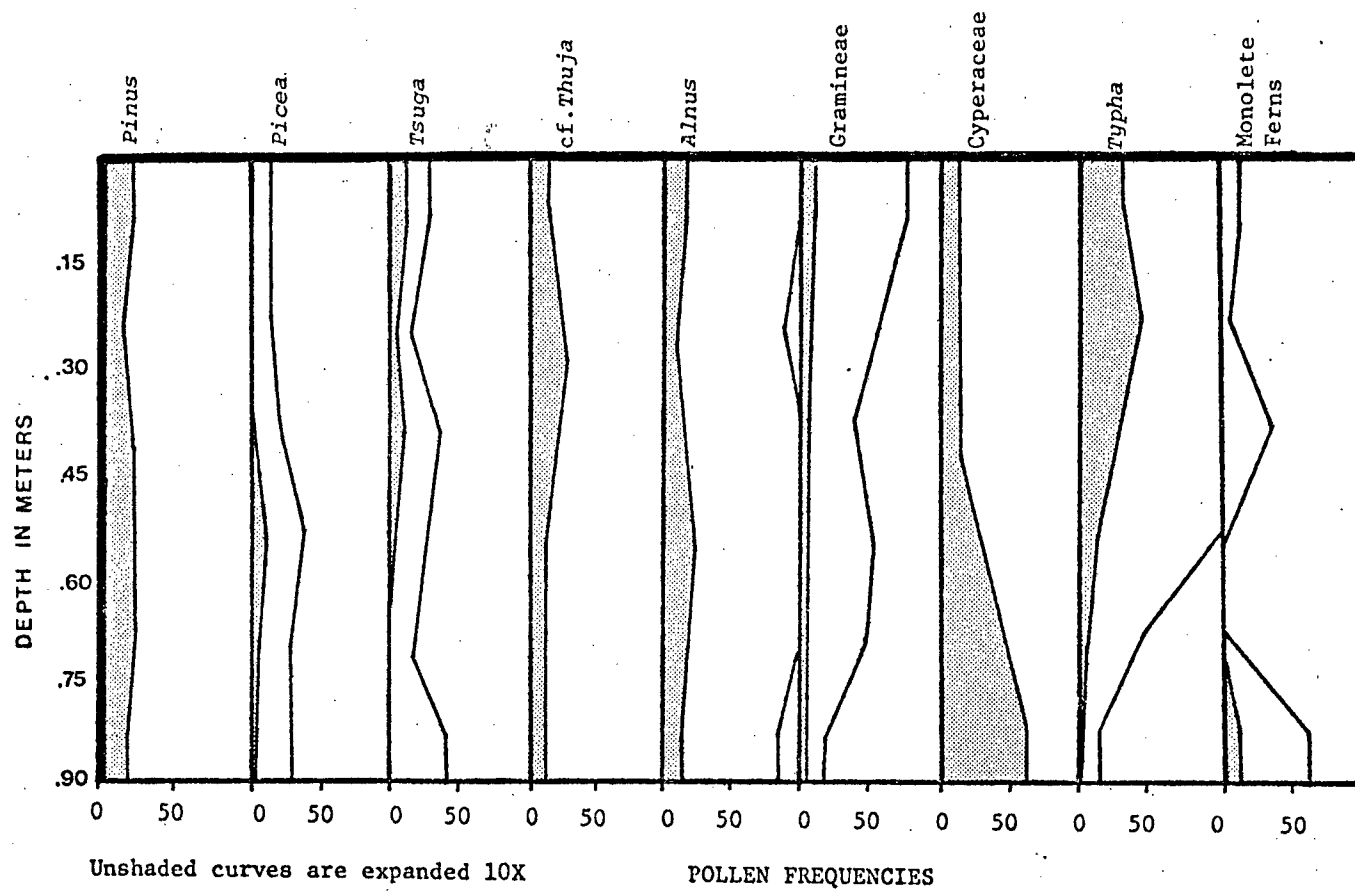
26a) sites DF 1&2, Scirpus zone26b) site DF 3, Typha zone26c) site DF 4, Carex-Potentilla zone

Figure 27: Pollen diagram of major species in short core DF-5, Carex-Potentilla zone, intertidal delta-front.



CHAPTER 5: CORE CBB FROM CENTRAL BURNS BOGIntroduction

The following three chapters (5, 6, 7) contain the results and discussions of palynological and macrofossil analyses of the three cores (CBB, BBDC, DNR) examined in detail. The results obtained from core CBB are presented first because this core was taken at a site near the top of the central cupola of Burns Bog (Fig. 10), an area likely to contain the most typical and complete sequence of raised bog development. This core is used as a reference for the two subsequent cores that were taken from the edges of the bog, where bog succession has been affected by various disruptive factors.

Methods

The core was obtained from a shallow, flat-bottomed, Sphagnum tenellum-Rhynchospora alba depression. The top 1.50 m of the profile was sampled in 5 cm intervals from the wall of a pit excavated in the peat because the poorly consolidated deposits would not remain in the sampling tube. The remaining interval (1.50-6.75 m) was cored using a 5 cm diameter by 50 cm long piston corer. Extruded cores were divided into 10 cm samples, immediately placed into plastic bags, and stored in the laboratory after addition of a few drops of phenol (except to samples for radiocarbon dating) to prevent fungal and bacterial growth. Samples for radiocarbon dating were obtained at 5.50-5.30 m and 2.10-2.00 m and later sent for processing to Teledyne Isotopes, Westwood Laboratories, Westwood, New Jersey.

In the laboratory, samples were split in half lengthwise and a 1 cm x 1 cm channel removed from the center of one of the halves for pollen analysis. This material was processed according to the standard pollen preparation outline in Ch. 4, and mounted in silicone oil. Part of the remaining unprocessed material was screened for macrofossils.

Pollen and spores were identified and counted along transects to obtain a total of 400 if possible. Monolete fern spores were counted along with other palynomorphs; however, they were excluded from the total because their numbers were sufficiently high to completely suppress the other species.

Pollen Diagrams

In recent times palynologists have been turning to computers to assist in calculating relative pollen percentages and plotting pollen diagrams (Voorrips, 1973; Squires and Holder, 1970). The time required to produce pollen diagrams is much shorter, and the resultant diagrams much more precise. In the present study calculations of all pollen values have been made by using a PDP11 Digital Data Corporation Computer and the pollen diagrams have been plotted by a Calcomp plotter, both within the Biology Data Center at the University of British Columbia, Vancouver. Programs were written for calculating pollen percentages and absolute pollen concentrations (see Appendix-2), and the results arranged so that a canned plotting program (SPLOT Lauriente, unpublished) could be used. Relative pollen diagrams including all major species were obtained for each core. These were plotted out directly by the Calcomp plotter, and are presented here in essentially unaltered form. To improve presentation of data, as well as to

examine relationships among certain groups of pollen (e.g. AP, NAP, AP - Pine), the program for calculating pollen percentages was designed so that by removing or adding sets of data cards, separate diagrams could be plotted for the groups of particular interest, independently of the percentages of others. Manual or calculator-assisted determinations for many different combinations of species can be very time consuming and have usually been done to the level of distinguishing fluctuations within regional and local pollen groups. Also, some workers have separated out groups that they thought were of climatic significance, such as those indicating wet or dry conditions (Sears and Clisby, 1955).

In the present study, various groups have been plotted independently from the main pollen diagram. First, all of the arboreal pollen types, excluding pine, are presented in one diagram. These species do not appear to be major constituents of local site environments (except in core DNR). In most cases they seem to be derived from regional or in some cases extra-local sources (sensu Janssen, 1973). Pine is excluded because it forms part of local bog vegetation. Removal of local fluctuations in pine gives a clearer picture of changes occurring in other forest types. A separate AP diagram including pine is also included, since in the lower sections of cores, before pine appears locally on the bog, it can be considered part of the regional pollen component. All other pollen and spore types (excluding monolete ferns, see above) are considered to be local shrub and herb layer constituents (local NAP). Generally, these reflect the local successional changes that accompany the processes of bog formation. Most of the local species have probably been significant components of in situ communities recorded in the cores. As in the complete pollen diagram, monolete Poly-podiaceae have been excluded from the NAP sums.

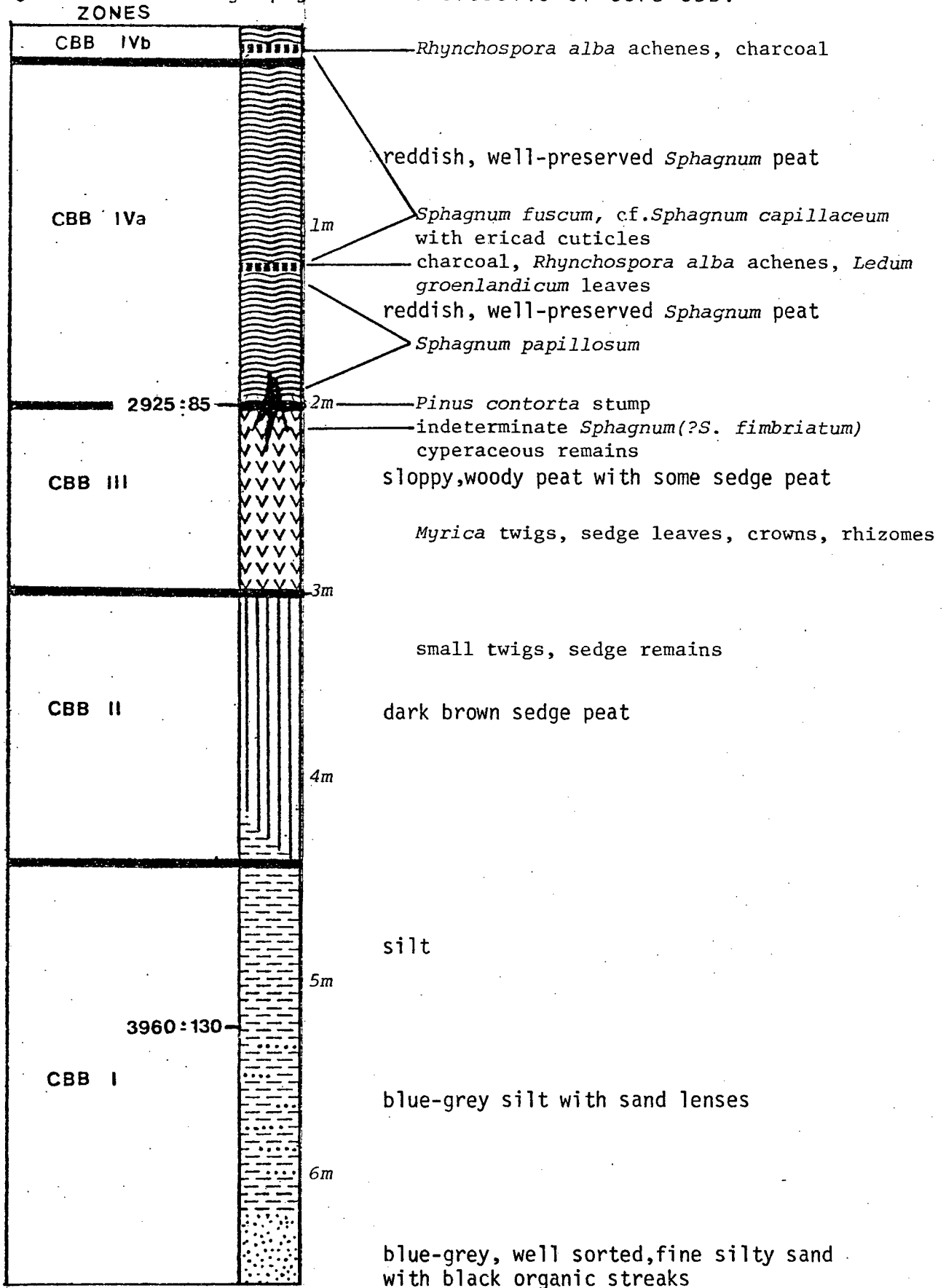
Results and Discussions

Stratigraphy and Radiocarbon Dating

The stratigraphy of the bog at this site is illustrated in Fig. 28. Basically, the bottom 1.75 m (6.75-5.00 m) records a gradual change in sediment type from grey-blue, silty sands to grey silts. Black organic streaks are present, particularly in the lower parts, with increasing amounts of organic material towards the top. The upper part of this interval, 5.10-5.30 m was radiocarbon dated at 3960 ± 130 years BP (I-9594). The next .8 m (5.0-4.20 m) is characterized by grey-brown organic silts which change to brown peaty silts. At 4.20 m the sediments become brown, crumbly peats with woody fragments, gradually changing to slightly silty sedge peats at 3.75 m. These continue up to 3.00 m, grading into a 1.00 m long interval of sloppy, woody peats mixed with sedge leaves and rhizomes. At 2.00 m, the first red, fibrous Sphagnum peats were radiocarbon dated at 2925 ± 85 years BP (I-9593). These Sphagnum peats contain several woody phases; one occurs just before 1.25 m, followed by 2 cm of charcoal. From .20 m to .10 m there is a layer of dense, dark-brown peat, also containing charcoal lenses. Above this there is .05 m of coarse, dark peat, .02 m of Rhynchospora remains, capped by .03 m of living Sphagnum tenellum.

The radiocarbon date on the start of Sphagnum bog conditions indicates that most of the time (3,000 years) represented in the core was taken up by the Sphagnum bog phase. The peat accumulation rate during this interval works out to be 6.67 cm/100 years. This value is much lower than the approximately 82 cm/100 years determined for actively growing hummocks of Sphagnum fuscum and Sphagnum capillaceum from a recently disturbed area in

Figure 28: Stratigraphy and macrofossils of core CBB.



Burns Bog (Biggs, 1976). The overall accumulation rate is even slightly less than the minimum accumulation rate (7 cm/100 years) in a wet almost barren depression at the same site. Apparently, the low, overall accumulation rate (6.67 cm/100 years), is a result of compaction, intermittent Sphagnum growth, decomposition and burning during the history of the site. The rate compares favourably with that obtained for Jesmond Bog, southwestern British Columbia (7 cm/100 years) (Nasmith et al., 1967), a Minnesota peatland (5 cm/100 years), investigated by Heinselman (1963), and for British peat bogs (2-8 cm/100 years) (Walker, 1970). However, it is less than that obtained for certain bogs in the northeastern United States (10-20 cm/100 years) (Cameron, 1970).

Palynomorph and Macrofossil Zonation for Core CBB.

The complete diagram, showing the distribution of 38 pollen and spore groups in core CBB, is presented in Fig. 29. Four major zones are distinguishable in the diagram (CBB I-IV), with zone CBB IV divided into two sub-zones, a and b.

ZONE CBB - I, (6.75-4.40 m):

This interval is characterized by constant high percentages of conifers, particularly Pinus. Although not indicated in the diagram, the majority of the pine pollen belonged to the Pinus contorta type, with only a few belonging to the Pinus monticola type. Picea, Tsuga heterophylla and Pseudotsuga pollen each represent from 5-15% of the spectrum. Many of the conifer grains have a battered appearance, indicative of considerable transport. Also present are numerous reworked, Tertiary pollen grains (Fig. 33) recognizable on the basis of their amber to brown colouration

after safranin staining. Surprisingly their frequencies reach up to 25% of non-Tertiary pollen and spores. Reworked palynomorphs include: Pinus, cf. Picea, Tsuga, cf. Cedrus, Abies, Carya and Juglans and the form-genus Cicatricosisporites. Overall, the arboreal component (AP) (Fig. 31) dominates the assemblage, averaging around 80%. This seems to indicate little deposition from local NAP sources. These features of the AP, viz. high Pinus, battered grains, reworked Tertiary palynomorphs, low NAP, indicate that much of the AP assemblage in this interval has been derived from the pollen load of the waters of the Fraser River as occurs in intertidal delta-front and estuarine environments (see Ch. 4).

Zone CBB - I is also characterized by significant percentages of Cyperaceae, Typha and Rosaceae pollen. Cyperaceae are most abundant (30%) near the bottom, whereas Typha tetrads reach relatively high values (10%) in the upper half. The Rosaceae pollen, reaching 60% of the NAP (Fig. 32), appear to belong to Potentilla, on the basis of the finely striate ornamentation of the exine. It seems likely that this represents Potentilla anserina subsp. pacifica, which is common in the upper intertidal marsh of the delta-front as well as in other localities along the coast. Modern pollen studies (Ch. 4) indicate that the percentages of Typha and Potentilla in the diagrams can be expected in vegetation dominated by either species. Increases in both types in the core are accompanied by decreases in Cyperaceae pollen, particularly in the upper part of the interval. Other marsh indicators include: Malvaceae (cf. Sidalcea hendersonii) and Equisetum as well as Cyperaceae.

At the boundary between zone I and zone II, fern spores occur in very high frequencies, being up to 12 times as abundant as the total of all

other pollen and spores. Although surface samples from the delta-front reveal some concentration of monolete fern spores (cf. Athyrium), the high numbers, together with many sporangia and scalariform tracheids, strongly suggest that Athyrium filix-femina was growing at or near the core site. A convincing analog for this situation has not been observed; however, sparsely dispersed clumps of this fern grow in Spiraea thickets along the Pitt River, some 30 km northeast of Burns Bog. During at least part of the fern spore peak in core CBB, Spiraea is also present. In addition, Athyrium produces copious quantities of spores. This indicates that only a small number of plants growing in an area is required to achieve high spore frequencies in the sediments.

Other features characteristic of CBB-I include the cf. Periconia fungal conidia and the chitinous tests of microforaminifera (Fig. 33).

The identifiable macrofossil record (Fig. 28) is poor, with mostly rush-like and sedge leaf and rhizome fragments incorporated into the sediments.

An analog for zone CBB-I can be found on the existing intertidal marshes of the Fraser River delta-front. In the Scirpus zone (Forbes, 1972), tidal activity is most pronounced between slightly elevated tussocks of Scirpus americanus and Triglochin maritimum. These trap the finer sediments while sand is moved back and forth in the low spots by tidal action, resulting in the deposition of lenses of sand in the silts. The organic content is low, restricted to burial of in situ Scirpus americanus and Scirpus palludosus remains by silts and fine-grained well sorted sands derived from the Fraser River. Typha latifolia stands occur near fresh water sources, such as near river channels (Fig. 25); on the basis of

surface pollen spectra even low percentages of Typha pollen indicate stands of this species nearby.

In the pollen spectra of the sediments of the Fraser River analog, Pinus and Picea from river waters predominate. Local NAP pollen is characterized by Cyperaceae. These deposits form the base for any plant succession that occurs as the actively growing delta-front moves away from a site. The upper part of CBB - I equates more closely to vegetation shoreward of the Typha zone (Fig. 25), or shoreward of the Scirpus zone where Typha stands are absent (i.e. away from river channel mouths). Carex lyngbeyi is the most characteristic species with many other emergent aquatics very abundant (Forbes, 1972). Potentilla anserina subsp. pacifica also grows here, although the pollen percentage preserved is low.

ZONE CBB - II (4.40-3.00 m):

At the transition from CBB - I to CBB - II Pinus, Picea and Pseudotsuga levels drop sharply, whereas Tsuga remains constant. Cf. Thuja pollen occurs in trace amounts. Alnus levels gradually increase throughout the interval. The sudden conifer drop is accompanied by a large increase in Cyperaceae pollen to 60-70%. A peak in Spiraea pollen occurs in the bottom half of the zone, while at the same time monolete fern spores (cf. Athyrium) reach the highest values recorded in the core.

The arboreal diagram (Fig. 31) clearly shows that the tree pollen types fall into two categories. Picea, Pseudotsuga and Pinus drop markedly in the transition to CBB - II. The second group of Tsuga, cf. Thuja, Abies and Alnus either rises sharply or stays the same. These four are species characteristic of either the delta lowlands or the nearby surrounding uplands. This suggests that in this zone, the arboreal pollen being

deposited was derived from the regional, atmospheric pollen rain, and not from river sources. This coincides with the change in deposition from dominantly mineral sediments in CBB - I to dominantly organic sediments in CBB - II. The overall drop in the AP (Fig. 31) is probably a result of: a) decreased fluvial input of pollen and sediment; and b) increased pollen deposition from local NAP pollen contributors, particularly Cyperaceae.

The NAP diagram (Fig. 32) clearly shows domination by Cyperaceae accompanied by sedge leaf and rhizome remains in the macrofossil record, strongly suggesting sedge swamp conditions. The Spiraea peak at the bottom of the interval implies that thickets of Spiraea were probably close-by. Finally, near the top of the zone it appears that grasses may have become established locally.

The very high monolete fern spore values continue from the zone below, and are still associated with Spiraea. Even though present in trace amounts, Lonicera pollen in this zone and in the upper part of CBB - I suggest that Lonicera involucrata was growing in the sedge marshes (fens) of the area, perhaps along abandoned channels or in backwater habitats of the river.

Reworked Tertiary pollen types (Fig. 33) disappear at the beginning of zone CBB - II. At this same horizon, cf. Dactylaria and cf. Curvularia fungal microfossils, characteristic of riverine marshes, appear for the first time. Trace quantities of microforaminiferal tests and cf. Periconia indicate the last time for intertidal delta-front influence in the core. Diagnostic macrofossils (Fig. 28) are scarce, with the sedge leaves suggesting that the cyperaceous pollen is that of Carex. Twiglets in the same sediment appear to resemble those of Spiraea, although Spiraea pollen occurs

in relatively low amounts (see Ch. 4).

Vegetation of zone CBB - II is not obviously represented in the present delta, probably because the areas it would occupy have been diked and turned into farmland. However, the Pitt River Delta, which is presently building into the southern end of Pitt Lake (G. Ashley, personal communication) serves as a likely analog. In the wet meadows flanking the Pitt River, sedges (Carex rostrata) and grasses (Calamagrostis canadensis) grow on silty peats (Barnard, 1975). When lake levels are high, these fens are flooded with up to .30 m of water. The degree of flooding decreases with distance from the lake and the river, with the formation of clumps of Spiraea douglassi and Myrica gale. At sites still farther from the river, Spiraea and Myrica combine to form continuous thickets, sometimes accompanied by Malus fusca and Lonicera involucrata (Barnard, 1975).

In short it appears that zone CBB - II records wet sedge fens which show signs near the top of the zone of developing shrubby vegetation.

ZONE CBB - III (3.0-2.0 m):

In this interval the levels of arboreal pollen change little from zone CBB - II, except for increases in cf. Thuja. This indicates no major fluctuations in regional or lowland forests. At the transition from CBB - II to CBB - III, Cyperaceae pollen levels drop suddenly, followed by a gradual increase to reach previous values near the top of the zone. Most prominent in this interval is the 90% peak in Myrica pollen followed by a 10% peak in Spiraea. The overwhelming dominance of Myrica pollen along with Myrica stems, rhizomes and seeds (Fig. 28), clearly indicates a Myrica shrubland. Subsequently Spiraea thickets recurred with Ledum groenlandicum (Ericaceae

tetrads less than 30 μm in diameter) appearing near the top of the zone. Cyperaceous pollen also becomes dominant again, along with Spiraea and grasses. The first significant Sphagnum spores, together with decomposed Sphagnum leaves of the Sphagnum fimbriatum type near the top of CBB - III indicates Sphagnum colonization in this area.

Cf. Van Geel Type 55 (V.G. 55) fungal spores (Van Geel, 1976a) are restricted to the upper end of this zone. Gelasinospora spores indicate humification during the Spiraea peak.

In general, then, zone CBB - III was deposited during a Myrica-Spiraea-Ledum shrub phase containing areas of sedges in the early stages, and occupied by Sphagnum mosses in the closing stages.

Significantly, in the Pitt River wetlands there is a very similar vegetation assemblage in the transition between the sedge-grass wetlands, analogous to CBB - II, and the vegetation of a small area of raised bog (Pitt Lake Bog), developed on the lowlands (Barnard, 1975). Islands of Myrica and Spiraea appear within the sedge-grass marshes, becoming more numerous nearer the bog. Significantly in terms of a situation analogous to CBB - III, Sphagnum fimbriatum occurs within the Myrica-Spiraea shrubland. Although this is a mesotrophic species (W. B. Schofield, personal communication), its occurrence implies that Sphagnum species can become established in such habitats. Sphagnum palustre also occurs, but is more abundant with Ledum. The Sphagnum leaves that are preserved in CBB - III with Myrica and Spiraea appear to be of the Sphagnum fimbriatum type, although they cannot be definitely identified. At the transition from CBB - III to CBB - IV, Ledum tetrads appear, a situation quite analogous to the occurrence of Ledum stands between Myrica-Spiraea shrubland and Sphagnum bog at the edge of Pitt Lake Bog.

ZONE CBB - IV (2.0-0.0 m):

This zone is characterized by assemblages dominated by pine and Sphagnum, together with significant numbers of Ericaceae. Two subzones are distinguishable: subzone a) (1.9-.2 m) with more or less constant frequencies of Tsuga and other conifers except pine; and subzone b) (.20-0.00 m) with sharply reduced conifer levels (except pine), and sudden alder and grass increases.

Subzone IVa shows an increase in arboreal pollen over that of CBB - III. This can be attributed to the jump in pine, suggesting that Pinus contorta had colonized the bog around the core site. A pine stump was recovered at the 2.00 m level at this site supporting this conclusion. The arboreal diagram (Fig. 31) shows this increase in pine as being gradual. Most of the other arboreal species except cf. Thuja also seem to increase during interval CBB - IV, but at different times. These relative rises appear to be attributable to the decline in alder and cf. Thuja from higher values at the beginning of the interval (Fig. 30).

Sphagnum is clearly the dominant NAP palynomorph, indicating the development of Sphagnum bog conditions (Fig. 32). This conclusion is further supported by the virtual disappearance of Cyperaceae and the presence of notable amounts of Ericaceae tetrads, particularly in the lower parts of the zone. Ledum-type tetrads dominate in the lower section. These tetrads are gradually replaced by those larger than 30 μ m in diameter, indicating the advent of species tolerant of wetter conditions such as Kalmia microphylla, Andromeda polifolia, Vaccinium oxycoccos and Vaccinium uliginosum. A thick charcoal layer at 1.20 m records a major fire that burned the preceding heathland.

Subzone IVb represents a very short interval where a sudden drop in conifer pollen (except pine) is accompanied by a pronounced increase in both alder and grasses. This is almost certainly the result of the arrival of European man, who cleared and logged the surrounding areas. Increases in pine, cf. Rhynchospora and Pteridium along with a decrease in Sphagnum seem to be the result of burning and partial draining of the local bog area. This was accompanied by the development of a Rhynchospora alba-Sphagnum tenellum hollow at the core site. The sudden rise in grasses may also result from relatively good preservation in the very wet conditions at the site, in addition to increased grass growth on cleared land (see Ch. 4).

A host of new fungal and rhizopod types (Fig. 33) appears in zone CBB - IV, the most characteristic being Desmidiospora, a constant associate of Sphagnum. Many of the others correspond to those reported by Van Geel (1973) from a raised bog in West Germany. Cf. V.G. 55 fungal spores are very abundant but of unknown ecological significance. Gelasinospora and V.G. 3 fungal microfossils are associated with fire horizons or humified layers, reflecting changes in soil conditions (Van Geel, 1973). Macrofossil recovery varies throughout, with best preservation and greatest diversity associated with charcoal and humified layers. Right after the advent of Ledum, Sphagnum peat begins to accumulate in the deposits at the base of zone CBB - IV. Sphagnum macrofossils at this level have been identified as very papillose Sphagnum papillosum which in British Columbia is an oceanic type, characteristic of the bogs of the west coast of Vancouver Island (W. B. Schofield, personal communication). Sphagnum papillosum of the very papillose type is not currently growing in Burns Bog, suggesting that the habitat was more oceanic than at present. Above the S. papillosum

layer, the peats seemed to have been formed from Sphagnum fuscum and Sphagnum capillaceum.

At the edge of Pitt Lake Bog, the transition from Myrica-Spiraea thickets into Sphagnum bog is also marked by the development of Ledum. However the attendant Sphagnum species in this region is Sphagnum palustre. With increasing boginess, Sphagnum capillaceum starts to form hummocks.

The large Pinus contorta stump uncovered at the 2.00 m level in core CBB exhibits the characteristic low growth rates and oscillating poorer and better growth expected for an area of active Sphagnum development (see Ch. 2). It is interesting to note that in the Pitt Lake Bog, Pinus contorta does not grow outside the Ledum-Sphagnum band around the bog periphery. This implies that certain soil conditions perhaps related to pH and water content must be established before pine will colonize (Birks, 1975).

The two major fire horizons in CBB - IV are of interest because they support observations made on the effect of fire in the present bog environment (Ch. 2). In both cases, the fire horizons are preceded by peaks in Ledum-type pollen and are followed by sudden drops in Sphagnum spores and Ledum, along with the first appearance of Rhynchospora alba achenes. Abundant Rhynchospora indicates the formation of a shallow depression with low accumulation rates until recolonized by Sphagnum. Immediately after the fire at 1.22 m, all arboreal pollen percentages rise suddenly, apparently a response to the elimination of local NAP. Pinus recovers somewhat later, to levels twice as high as before the fire, and then gradually decreases as Sphagnum recolonizes the burned surface and restricts nutrient uptake (see

Ch. 2). The fire(s?) in the top .20 m have left the site with the same Rhynchospora dominated cover as just after the fire at 1.22 m.

Summary and Conclusions

The central part of Burns Bog has formed on intertidally deposited silts of the Fraser River Delta. As the delta-front emerged more than 4,000 years ago, brackish water conditions supported emergent aquatics such as Scirpus and Typha. With decreased influence from the sea and the river, sedges became established in periodically flooded fens and organic accumulation replaced mineral deposition. This phase was followed by the advent of shrubs such as Myrica and Spiraea. Once a suitable substrate developed, about 3,000 years ago, Sphagnum spp. and Ledum groenlandicum took over, leading to the eventual establishment of a raised bog ecosystem. The fire horizons recorded by charcoal in the core were followed by temporary local disappearance of Sphagnum and appearance of Rhynchospora alba. The core also indicates that the regional AP, reflecting upland forests, remained unchanged until the advent of immigrants at the .20 m level, with subsequent increases in alder and grasses and decreases in all AP types except pine.

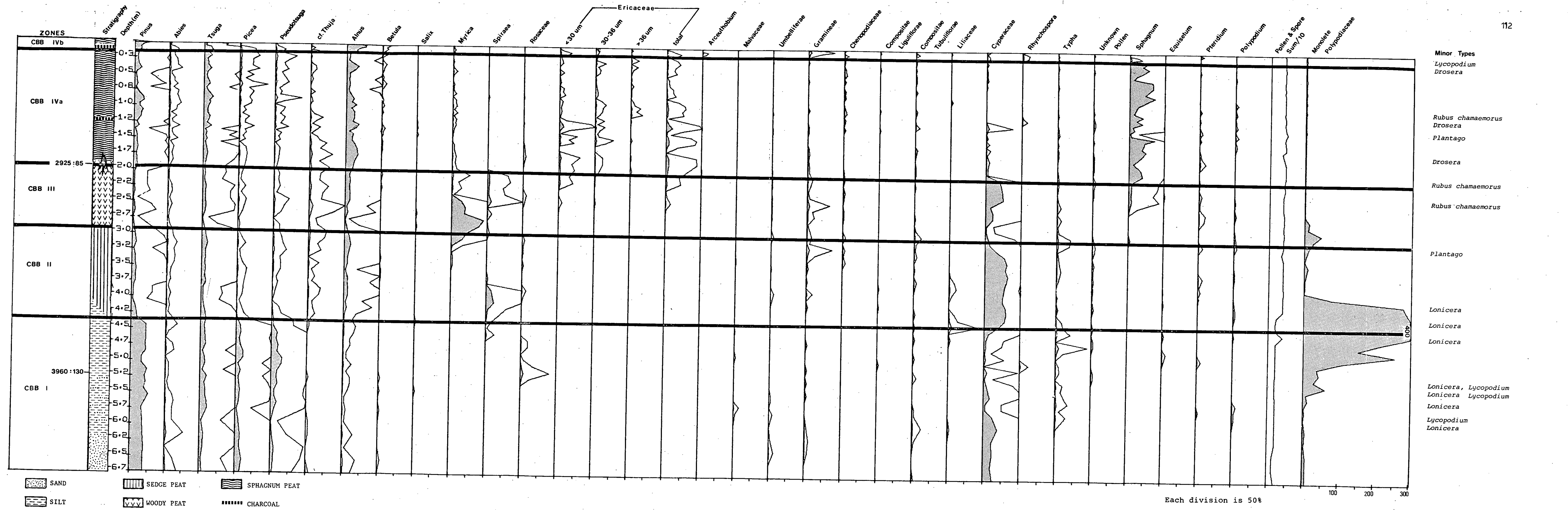
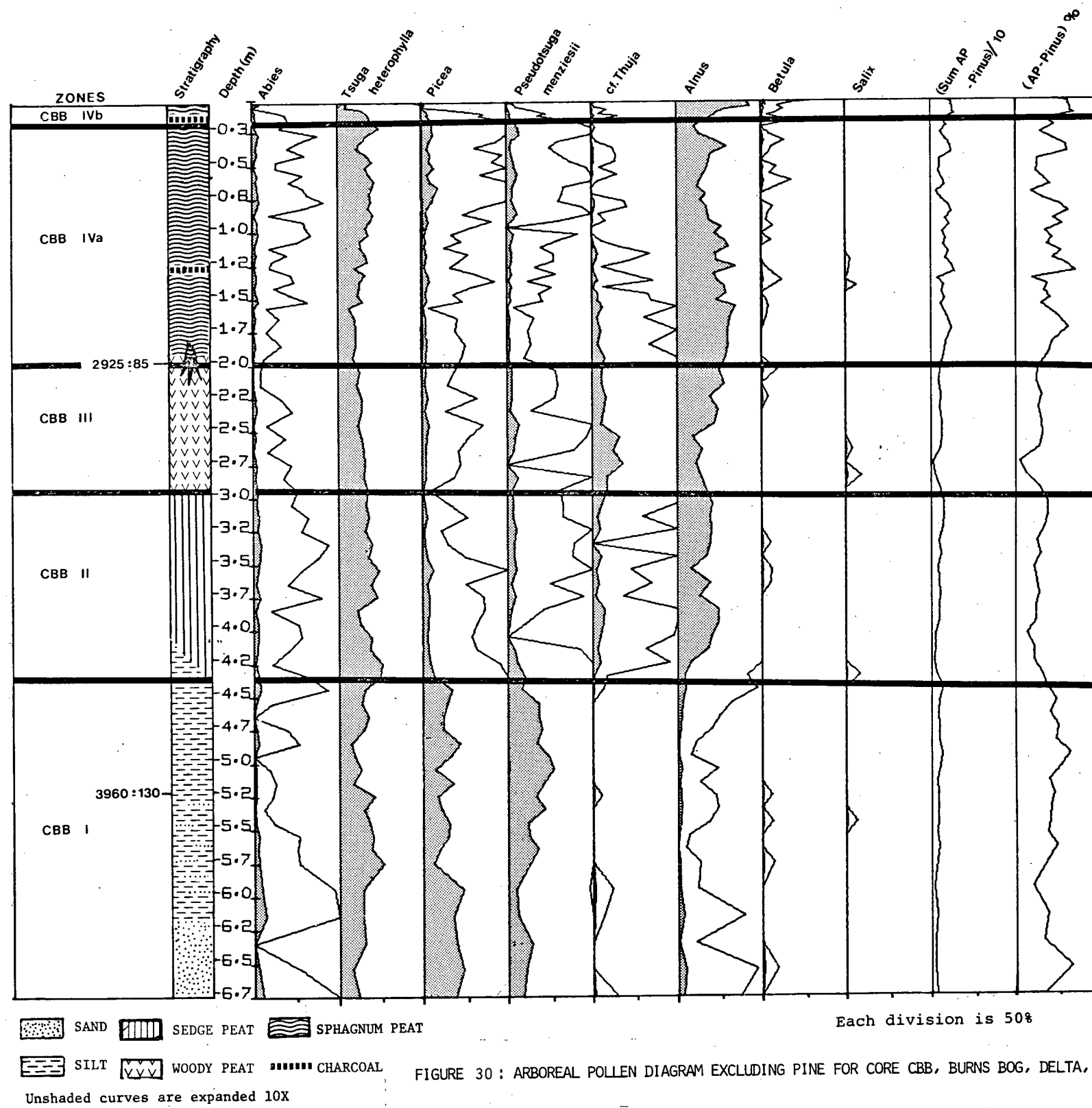


FIGURE 29: POLLEN DIAGRAM FOR CORE CBB, BURNS BOG, DELTA, BRITISH COLUMBIA.



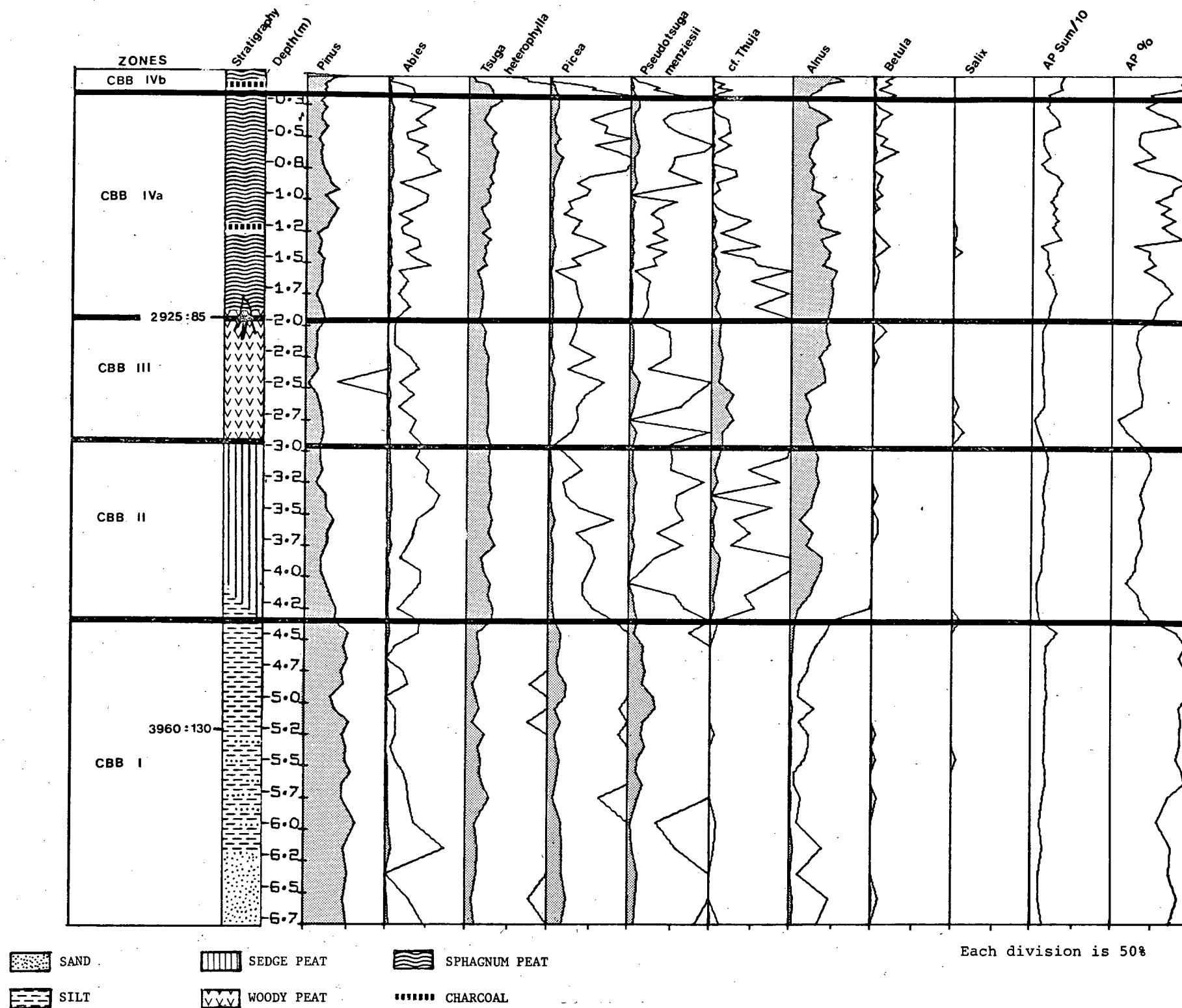


FIGURE 31: ARBOREAL POLLEN DIAGRAM FOR CORE CBB, BURNS BOG, DELTA, BRITISH COLUMBIA.

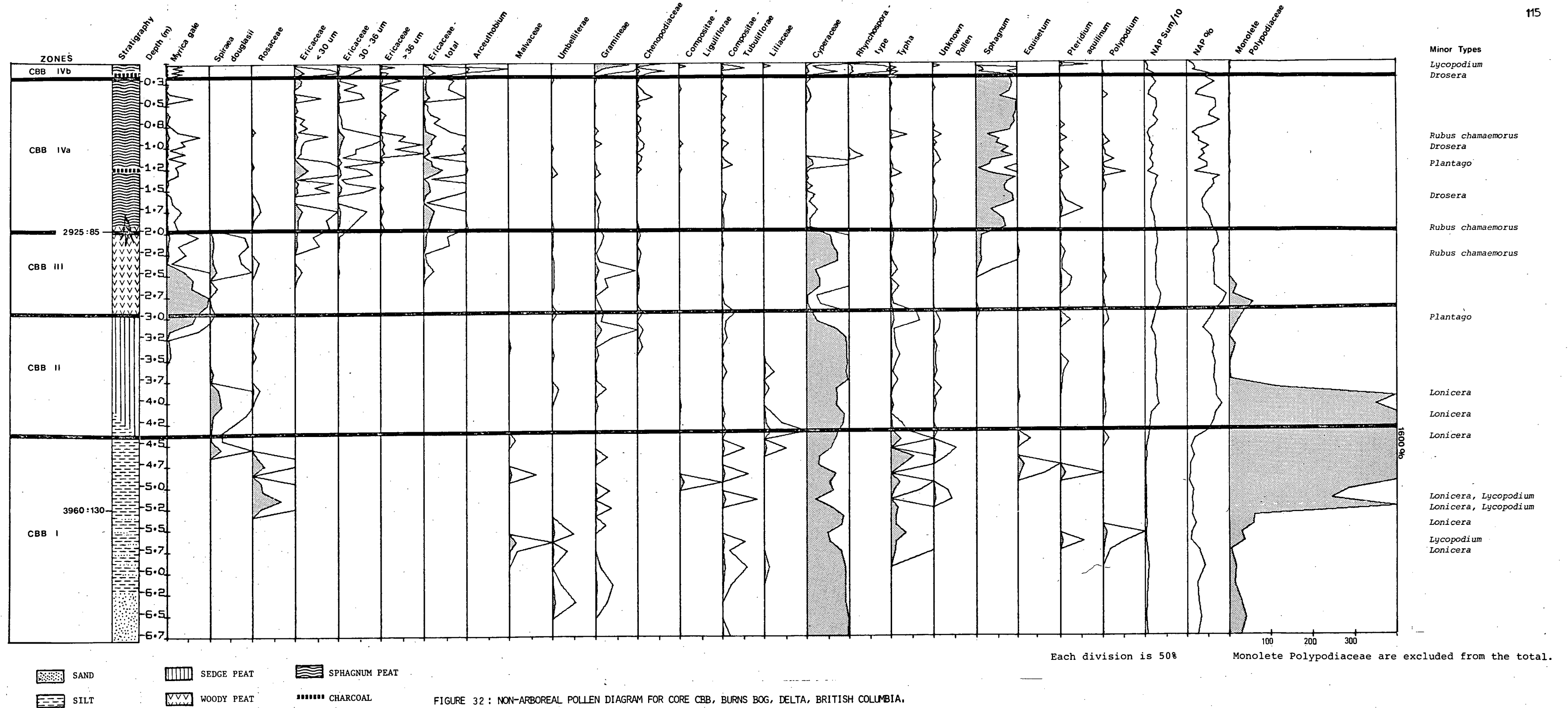
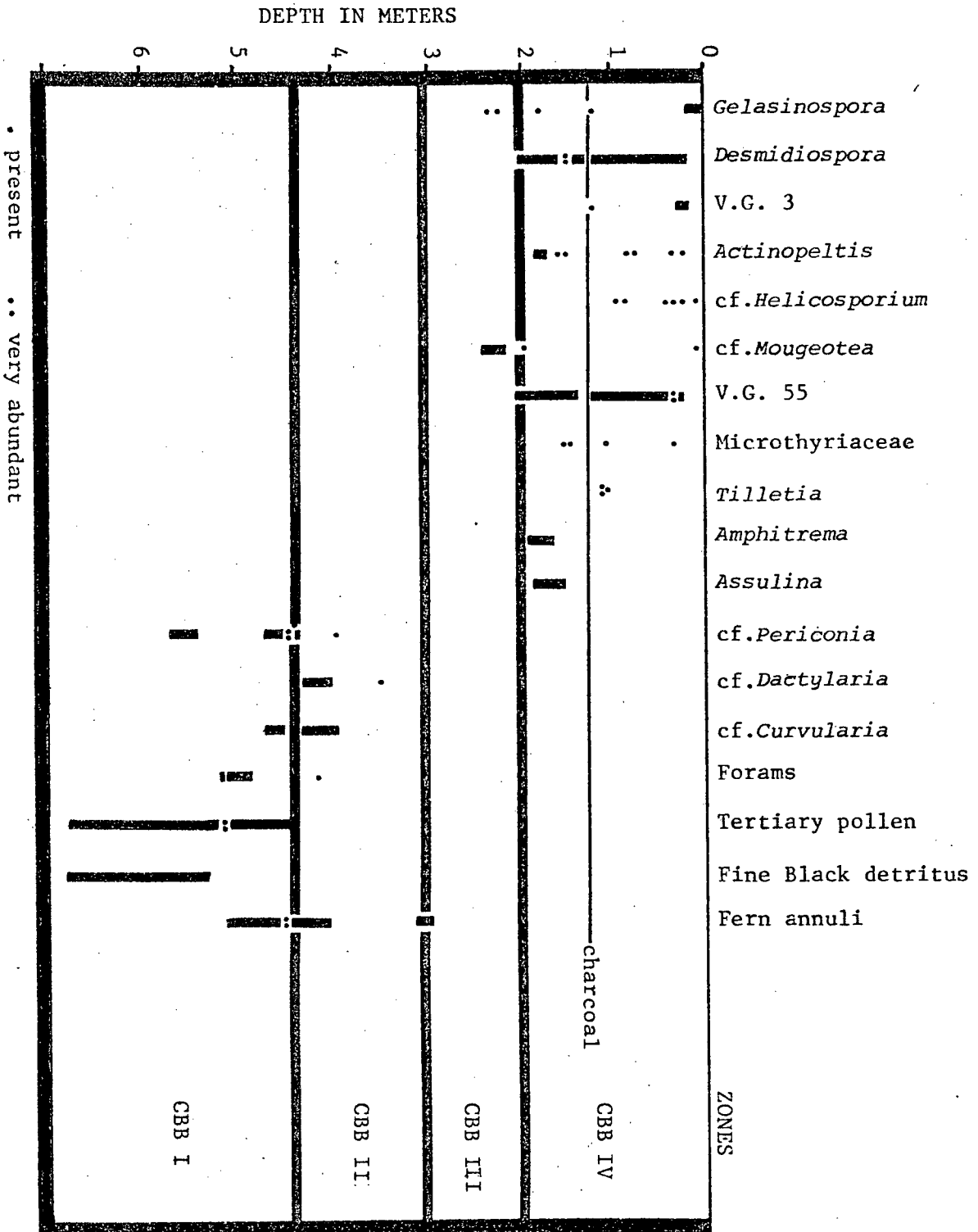


Figure 33: Palynomorph diagram for core CBB.



CHAPTER 6: CORE BBDC FROM WESTERN BURNS BOG

Introduction

Core BBDC was obtained from the southwest corner of Burns Bog adjacent to the Vancouver Sanitary Landfill Site (Fig. 10). This locality was chosen because of the necessity to collect information from the western part of the bog for completeness and before burial of this area by landfill. Dwarf Pinus contorta, Ledum groenlandicum and Sphagnum capillaceum are the major plants growing on the site.

Methods

The core was obtained in the same manner as core CBB (see Ch. 5). The samples were prepared using a modified procedure from that employed for core CBB and DNR, so that absolute pollen values could be obtained from both the volume and the weight of the sediment.

Absolute pollen

In palynological analyses, absolute pollen determinations can be made to obtain values of the actual numbers of pollen grains present in samples of known volume and weight. As such they also record the actual number of grains dispersed by the various species during a specific interval of time. If radiocarbon dates are obtained at various horizons throughout the core, the sedimentation rates for the various intervals can be calculated, and the corresponding annual pollen deposition determined (Davis, 1967). The absolute pollen determination removes the problems inherent in interpreting relative percentages in pollen diagrams.

It is apparent that for consistent results, sedimentation rates must be accurately determined by multiple radiocarbon dates on every core; constant sedimentation rates are assumed between dates. This condition is approximated in open lakes, where sedimentation is dominated by a constant vertical component (falling detritus → gyttja) and more or less uniform physical and biological turbation of sediments. Where such conditions do not exist, assuming constant accumulation rates is not a valid procedure. This is particularly true for cases that recorded rapidly changing environments such as those investigated in this study. Nevertheless absolute pollen determinations were made for core BBDC to discover the sorts of palynomorph concentrations characterizing the environments represented.

The samples were prepared using the standard procedure with the following modifications. First, the initial volume of the sample was determined by the following method. The sample was suspended in water and placed in a 50 cc graduated conical centrifuge tube and centrifuged for one minute at 7,100 rpm. The volume of sediment was read from the scale on the side of the tube. This technique, suggested by Faegri and Iversen (1965, p. 41), was used because extracting fixed volumes by the "plug" method of Mathewes (1973) was prevented by the fibrous nature of the peat deposits. After volume determination, the dry weight (oven drying at 80°C) of each sample was also determined.

The exotic pollen method (Benninghof, 1962) was chosen for absolute pollen determination because it does not require the time-consuming weighing of slides, and counting all grains on a slide as in the "volume" method (Mathewes, 1973). A standard solution of Sciadopitys verticillata pollen was employed as a source of the exotic grains. Sciadopitys was used because

it is reasonably distinguishable from native pollen and spore types and is available locally in large quantities. To prevent any confusion of Sciadopitys pollen with superficially similar Tsuga heterophylla pollen, the exotic grains were stained for one minute with a 1% solution of methyl green. The exotic grains were found to maintain their green colour in silicone oil if TBA, neutralized with a few grains of K_2CO_3 , was used in the final wash before mounting in silicone oil. Thus, the Sciadopitys grains were rendered easily distinguishable by both morphology and colour. The concentration of the exotic pollen solution, 7.62×10^6 grains per ml, was determined by using a corpuscle counting chamber (Improved Neubauer, Ultra Plane, Spotlite Counting Chamber, $1/400 \text{ mm}^2 \times .1 \text{ mm}$ deep, C. A. Hauser and Son).

A measured volume of pollen sample was "doped" with 100 μl of the exotic grain solution and mounted in silicone oil.

The fossil palynomorphs and the exotic grains were identified and counted to a total of 400 pollen and spores whenever possible. Then the following formula was applied to determine the absolute concentration of pollen and spores for each sample.

$$\text{Absolute pollen and spore concentration/cc} = R_p \times K / (R_v \times V_o)$$

$$\text{Absolute pollen and spore concentration/gm} = R_p \times K / (R_v \times W_o)$$

where; R_p = Number of fossil grains/Number of exotic grains

K = Concentration of exotic solution x Volume of exotic solution used

R_v = Volume of doped sub-sample*/Total volume of original prepared sample

V_o = Volume of original sediment sample after centrifuging (in cc)

W_o = Dry weight of original sediment sample (in grams)

*usually only part of the pollen residue prepared from a sediment sample was doped with exotic pollen.

Absolute pollen diagrams were prepared using a computer program written for the particular purpose (Appendix-2b).

Sediment analysis

Environments, as well as being characterized by microfossil and macrofossil assemblages, are also identifiable by sedimentary characters. To get an idea of the nature of the mineral sediments at the bottom of core BBDC, and thus a better idea of the environments in which they were deposited, the sand:silt:clay ratios were determined for selected samples.

The sand fraction was determined by wet sieving, whereas the percentages of the silt and clay fractions were obtained by the pipette method (Folk, 1968). Samples of 40-50 grams were taken at about .50 m intervals from the mineral deposits comprising the last 3.00 m of core BBDC. The sediments were disaggregated and dispersed in distilled water. Then they were wet-sieved at 210 μ m to remove large plant fragments. If any sand greater than 210 μ m was found, the residue was treated with H_2O_2 overnight, washed, oven-dried, and weighed. The material that passed through the 210 μ m mesh was similarly treated with H_2O_2 and sieved again at 63 μ m; then the grains greater than 63 μ m (sand fraction, Folk, 1968, p. 25) were oven-dried at 110-130°C and weighed. The total weight of the sand fraction consisted of all mineral grains greater than 63 μ m in size. The fines which passed through the 63 μ m mesh were dispersed in a weak Calgon solution, checked for flocculation, and then analyzed by the pipette method for

silt and clay fractions. The silt/clay boundary was set at 2 μ m (Folk, 1968).

Results and Discussion

Stratigraphy

The stratigraphic sequence for core BBDC (Fig. 34) begins with fine-grained silty sands. Gradually in the interval 5.50-5.00 m, the sediments change to silts with occasional sand lenses and black organic streaks. Silts continue up to about 4.20 m, where they are replaced by peats and peaty silts. At 3.75 m peaty silts and sands appear. These terminate sharply at 3.45 m, where they are overlain by silty sedge peats. The sedge peats continue to 2.50 m, where they are succeeded by heath peats. Sphagnum peat gradually takes over from about 1.10 m and continues to the surface, with some woody peat layers in the top .50 m. A pronounced layer of charcoal interrupts the Sphagnum peats at the .62 m level. Traces of charcoal also appear in the top .20 m.

Sedimentology

The sand:silt:clay ratios obtained from sediment analyses are presented in Table 4, and plotted in Fig. 35.

At the bottom of the core the sediments are composed of a 50:50 ratio of sands to silts. The proportion of sand decreases in the interval 5.50-4.50 m, with a concomitant rise in the silt component. The peaty deposits above (at 4.50-4.60 m and 4.00-4.10 m) show a significant clay fraction. At 3.50-3.60 m the proportion of silt increases markedly to 95% whereas the clay particles disappear.

The upward sequence of decreasing sediment size resembles the sediment-

Figure 34: Stratigraphy and macrofossils of core BBDC.

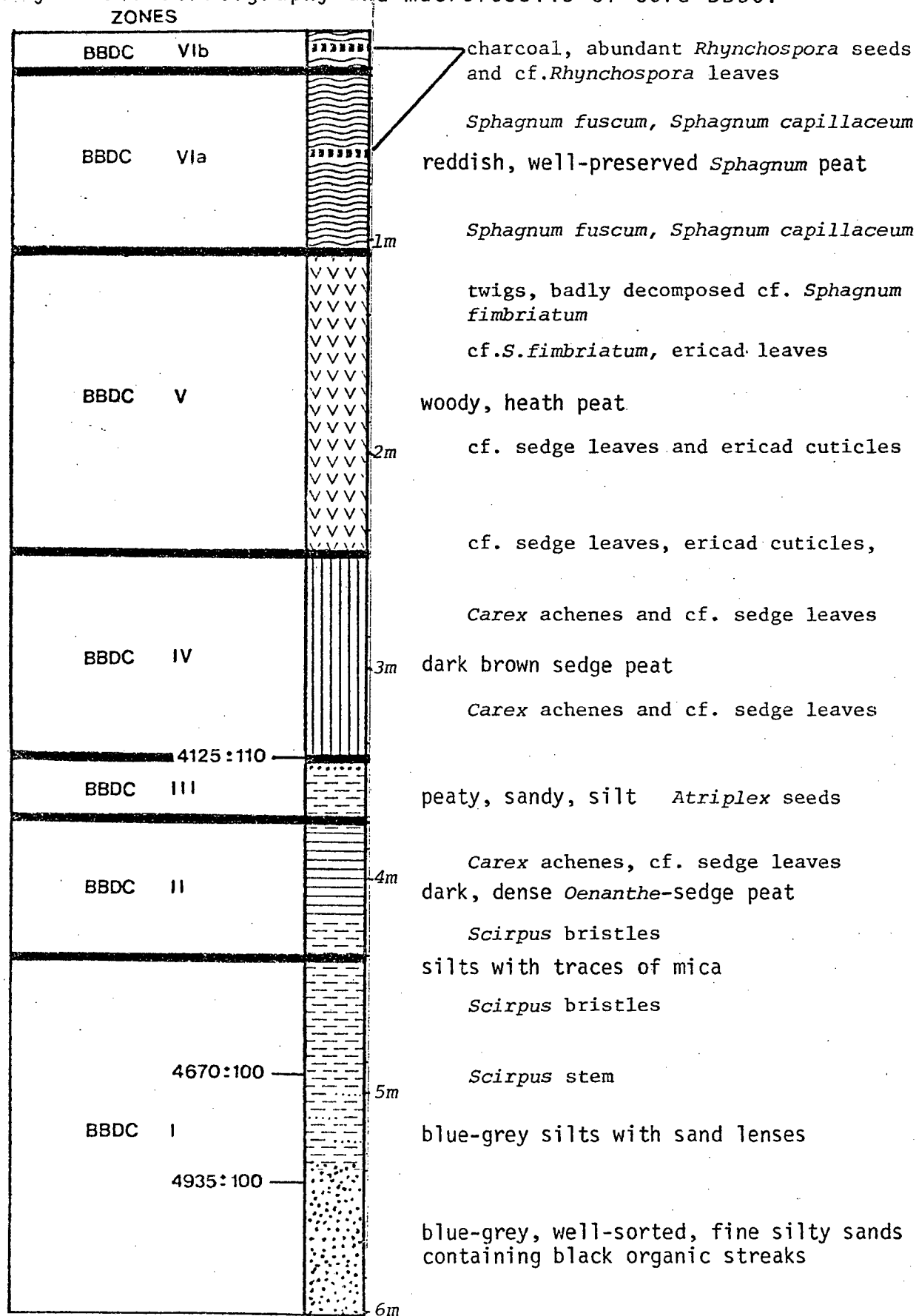


TABLE 4: SAND:SILT:CLAY RATIOS, CORE BBDC, BURNS BOG, DELTA, B.C.

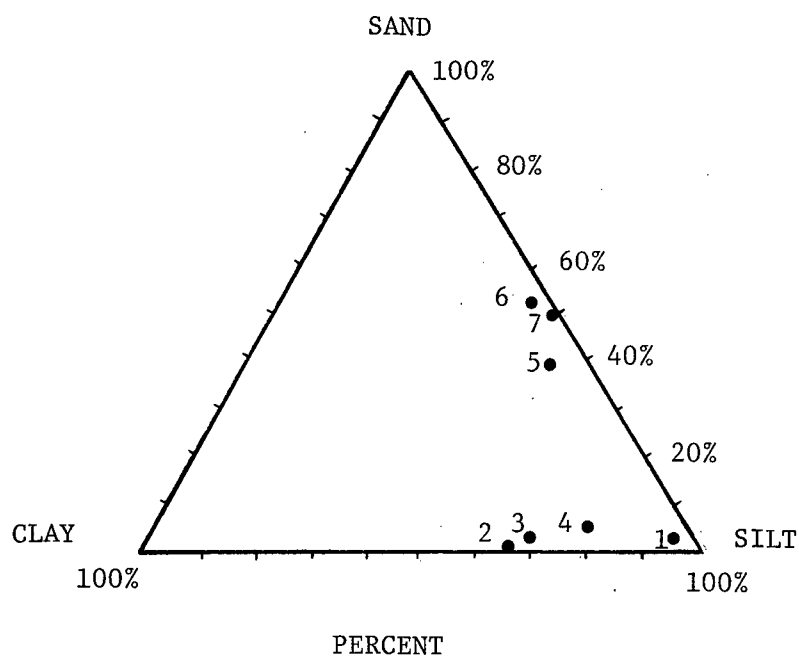
<u>Sample No.</u>	<u>Sample Depth (m)</u>	<u>Sediment</u>	<u>% Sand</u>	<u>% Silt</u>	<u>% Clay</u>
1	3.50-3.60	silt	3.0	95.0	2.0
2	4.00-4.10	silty peat	0.0	67.8	32.2
3	4.50-4.60	peaty silt	1.0	70.6	28.4
4	5.00-5.10	silt	5.2	78.6	16.2
5	5.50-5.60	sandy silt	38.2	53.4	8.4
6	6.00-6.10	silty sand	53.0	46.0	4.0
7	6.50-6.60	silty sand	50.0	50.0	0.0

sand - greater than 63 μm

silt - 2-63 μm

clay - less than 2 μm

Figure 35: Sand:Silt:Clay ratio triangle for selected samples from core BBDC.

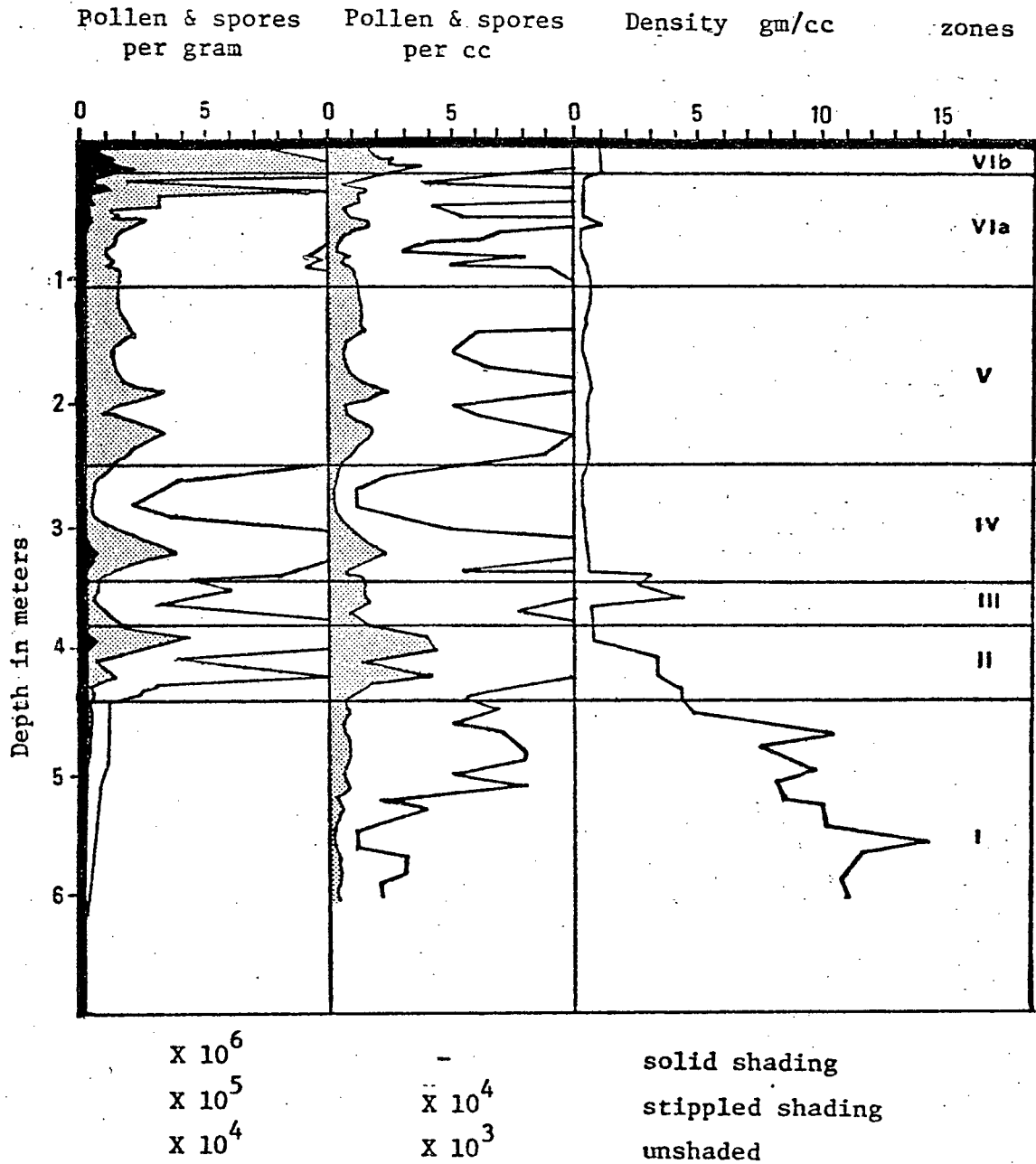


ary changes that can be observed in traversing shoreward from the edge of the vegetated intertidal brackish water marshes of the delta-front to the dike (Fig. 25). About 1.5 km seaward of the dike, tidal and wave activity is strong enough to sort out fine sands from silts and clays. The sands are left behind, and are deposited in small tidal channels among scattered clumps of Scirpus americanus and Triglochin maritimum. The silts and clays, on the other hand, are transported landward. Sand fractions of sediments on the seaward side of intertidal marshes of the Fraser Delta are usually around 50% (Luternauer and Murray, 1973; D. Grieve, personal communication). This sand level corresponds to the content of the intervals 6.50-6.40 m and 6.00-6.10 m in core BBDC. The few data available for sites closer to shore, and well within the marsh, indicate much lower percentages of sand (around 20%) (D. Grieve, personal communication). This is in agreement with the decreased proportion of sand observed between the two samples from 5.50-5.60 m and 5.00-5.10 m. Thus, moving shoreward, wave and tidal energy decreases and silts are deposited among Scirpus and Typha stands. Much less sand gets this close to shore and there are fewer tidal channels. Still closer to shore, fine silts and clays are deposited along with abundant organic material.

As noted in the next section, this sedimentologic sequence parallels closely the palynologic succession that shows a transition series from an assemblage of mainly river-derived palynomorphs through a zone of bulrush and cattail and finally to one dominated by sedges and umbellifers.

The high proportion of silts at the 3.50-3.60 m level indicates a major change in the sedimentary environment. In this interval, there was increased transportive energy with a proportionate decrease in peat

Figure 36: Absolute pollen and spore concentrations for core BBDC, Burns Bog, Delta, British Columbia.



accumulation.

From the radiocarbon dates at 5.45 m ($4,935 \pm 100$ BP, I-7629) and again at 4.97 m ($4,670 \pm 100$ BP, I-7628), the mean sedimentation rate for this interval is .17 cm/year. The marked difference in sand:silt:ratio from 5.45-4.97 m, however, clearly shows that this rate was not constant throughout the interval. The next higher interval, 4.97-3.45 m, terminating at $4,125 \pm 110$ BP, (I-7627), shows a considerably greater sediment accumulation rate of .29 cm/year. Large variations in rate probably also characterize this period, as both peats and silts are present. The upper 3.45 m of peats in this core were accumulated at an average rate of .08 cm/year.

Absolute Pollen: Results and Discussion

The amount of variation in sediment type and accumulation rate is so great that absolute annual pollen and spore sedimentation rates (Davis, 1967) cannot be calculated reliably. Consequently, absolute pollen data are discussed here only in terms of concentration of pollen and spores per gram and per cubic centimeter, and then related to sediment density (Fig. 36).

Zone BBDC - I: In this zone, pollen and spore concentrations are extremely low, ranging between 1,000 and 8,000 grains/cc and 1,000 and 10,000 grains/gm of sediment. These low concentrations could be expected in such dense, sandy silts deposited in delta-front environments (Muller, 1959). They result from both the relatively high sedimentation rate (approx. .17 cm/year), and the relatively low pollen productivity of the sparse local vegetation.

Zone BBDC - II: The peats overlying the previous silty deposits contain higher pollen and spore concentrations than these silts, ranging from

15,000 to 40,000 grains/cc and 30,000 to 440,000 grains/gm of sediment. These extremely high values per gram of sediment occur because of the light weight of the peats, the high concentrations of monolete fern spores, and probably because of increased contribution from local vegetation. These values are comparable to high concentrations obtained in Orinoco River backswamps (Muller, 1959).

Zone BBDC - III: The silty deposits from 3.80-3.45 m contain fewer pollen and spores (8,000-13,000/cc, 30,000-100,000/gm) than the peats below.

These decreased concentrations reflect the return to mineral sedimentation.

Zone BBDC - IV: The sedge peats that occur in this interval exhibit highly variable concentrations of pollen and spores. In the lower part, concentrations rise to 22,000/cc and 390,000/gm. However, in the upper part there is a marked decline in these levels to 1,000/cc and 20,000/gm. The reasons for such large changes in concentration within an apparently uniform peat type are not clear. Perhaps there were decreases in pollen productivity of sedge species, or perhaps preservation was markedly poorer in this upper interval.

Zone BBDC - V: The absolute pollen concentrations in the heath peats are much higher than in the sedge peats below, ranging up to 23,000/cc and 320,000/gram. Peaks and troughs do not seem to be associated with either major sediment density changes or differences in peat types. The increases are difficult to explain, other than as resulting from increases in local productivity and changes in preservation conditions.

Zone BBDC - VI: In this Sphagnum peat interval, concentrations begin at about the same levels as in the preceding heath peats, but increase substantially just after fire horizons, and also in the denser peats of the top .20 m. Peat accumulation rates are very low just after the fires,

especially in "Rhynchospora lows" (see Ch. 2). Pollen preservation appears to be good and is probably related to deposition in standing, acid water. This probably explains the marked increase at the 0.60 m horizon and in the top .20 m. Concentrations reach 35,000/cc and 2,100,000/gm, and are comparable to those obtained for lake gyttja by Mathewes (1973).

In summary, pollen concentrations change markedly throughout core BBDC, reflecting the varying sediment types and accumulation rates. Concentrations were most affected by changes in sediment type as reflected by density. The dense, basal, silty sands contain very low levels of pollen and spores. The numbers increase in peaty sediments because of the relatively low density of the peat and from increases in local pollen productivity. Highest concentrations are reached in the fine, dense, gyttja-like sediments of shallow post-fire depressions within the Sphagnum peats.

Pollen and Macrofossil Zonation

The pollen diagrams for core BBDC (Fig. 37; Fig. 38 (AP - pine); Fig. 39 (AP); Fig. 40 (NAP); Fig. 41 (Ericaceae)) have been divided into 6 zones with zone BBDC - VI subdivided into subzones a and b. These diagrams and the fungal spore and other palynomorph diagram (Fig. 42) are at the end of this chapter. The macrofossil records are shown in Fig. 34.

ZONE BBDC - I (6.10-4.40 m):

The AP of this zone (Fig. 39) is dominated by Pinus, with significant Picea, Tsuga, cf. Thuja and Alnus, and constitutes 50-80% of the total pollen and spore sum. The Salix peak at the end of the zone probably records a local stand of willow. Cyperaceae pollen makes up most of the NAP (Fig. 40) and is ascribed to either Scirpus americanus or Scirpus

palludosus on the basis of Scirpus sp. bristles in the sediments (Fig. 34). Other emergent aquatic types include Sagittaria, Malvaceae (cf. Sidalcea hendersonii) and Equisetum. Typha tetrads reach relatively high levels near the top of this zone.

The pollen and spore assemblage of BBDC - I is similar to that of CBB - I and probably indicates a very similar intertidal to estuarine delta-front environment. Other palynomorphs usually occurring in this environment are also present, including forams, hystrichospheres, reworked Tertiary pollen grains and both cf. Periconia and cf. Dactylaria fungal conidia, as well as fine black detritus (Fig. 42).

ZONE BBDC - II (4.40-3.80 m):

The boundary between BBDC - I and BBDC - II, as in core CBB, is placed where the AP drops and the NAP rises in response. This change reflects the decrease in importance of river-derived palynomorphs such as Pinus and Picea. Significantly, Tsuga does not decrease, probably indicating that proportionately more of this pollen was derived from the atmospheric pollen rain than either Pinus or Picea. The AP diagram (Fig. 39) shows that, at the top of the zone, Alnus increases at the expense of Abies, Picea and Thuja. This may represent the invasion by Alnus of river banks near the site.

Based on the occurrence of high Cyperaceae frequencies and abundant fossil achenes (either Carex lyngbeyi or Carex obnupta), it appears that sedges dominated the bottom part of BBDC - II. Umbelliferae replaced sedges in the upper part of the zone. Studies of pollen grain morphology of selected Umbelliferae indicate that this pollen was probably produced by Oenanthe sarmentosa (see Appendix 3, Fig. 51b). Oenanthe is commonly associ-

ated with Carex lyngbeyi and Potentilla anserina subsp. pacifica in a band of vegetation at the edge of the intertidal zone of the delta-front just landward of the Typha latifolia stands (see Ch. 4).

As in core CBB, monolete fern spores are numerous. There are also high numbers of cf. Periconia conidia with lesser amounts of cf. Dactylaria, cf. Curvularia and spiny Sigmopollis. The silty sediments, containing reworked Tertiary pollen grains, indicate that some river-derived pollen was still reaching the site.

This zone probably represents the high-water limit of intertidal delta-front vegetation, and may be environmentally correlative with the upper part of CBB - I. However, BBDC - II exhibits a greater degree of peat accumulation and less silt/clay sedimentation than the upper part of CBB - I.

ZONE BBDC - III (3.80-3.45 m):

Pollen of grasses and chenopods supplant those of Oenanthe and Carex in zone BBDC - III. Seeds of Atriplex triangularis are present along with chitinous tests of microforaminifera. These features, along with the presence of fine black detritus and forams (Fig. 41) indicate a salt marsh environment (see Ch. 4), and thus a marine transgression just before 4,125 ± 110 BP. At this time, fresh water from the Fraser River must have been prevented from reaching the site, perhaps by a shift in river channels. In this interval the AP changed only slightly from that below, with relative increases in Pinus, Picea, Abies and a gradual decrease in Alnus.

ZONE BBDC - IV (3.45-2.50 m):

At 3.45 m, fresh to brackish water conditions suddenly return to the site; as at this level there is a sharp contact between the sandy silts

below and the overlying silty sedge peats. High percentages of Cyperaceae, probably Carex (achenes - Fig. 34) indicate that a sedge swamp developed during this interval. Many of the microfossils characteristic of the upper part of BBDC - II return briefly, eventually disappearing midway through BBDC - IV.

In the AP, Tsuga replaces Alnus as the most abundant pollen. Tsuga may have colonized the swamp locally or Alnus sites on the banks of the river may have been destroyed by shifting channels.

ZONE BBDC - V (2.50-1.10 m):

The transition from BBDC - IV to BBDC - V is clearly marked by the appearance of large numbers of ericad tetrads, mostly of the Ledum type, together with some of the Empetrum nigrum type. At the same time Cyperaceae pollen virtually disappears. This zone also marks the first occurrence of Sphagnum spores. In the macrofossil record, sedge leaves and cuticles are replaced by ericad cuticles and twigs. Also there are well preserved Ledum leaves at the base of zone V. Branch leaves of the Sphagnum fimbriatum type occur, although there are no stem leaves to confirm the identification.

At approximately the 1.90 m level, the AP component doubles from 30-60% (Fig. 39). This rise is attributable chiefly to an increase in Pinus (compare Fig. 38 with Fig. 39), and probably reflects the invasion by pine of the site. Alnus increases noticeably at the beginning of the zone, accompanied by a drop in Tsuga. Again as in zone BBDC - I, this may reflect the development of fresh mineral substrates along nearby river channels.

There were also notable changes in the fungal spore assemblage from zone IV to zone V (Fig. 42). The appearance of Desmidiospora is particularly diagnostic, as it is known to characterize only Sphagnum/heath environments. The significance of the appearance of V.G. 55 is unknown as it has not been recovered from modern surface samples. It also appears to be restricted in the core to Sphagnum/heath deposits. Gelasinospora and V.G. 3 fungal microfossils both indicate some degree of humification; they do not appear until after Pinus became locally established.

The transition from sedge swamp to bog conditions in core BBDC differs from that in core CBB. In core CBB, there is a Spiraea-Myrica shrub stage preceding a very short Ledum interval. (see Fig. 32; end of CBB - III to beginning of CBB - IV). In BBDC, however, there is only a slight indication of Spiraea-Myrica shrubland at the bottom of zone V. The rest of BBDC - V seems to represent a Ledum heathland.

ZONE BBDC - VI (1.10-0 m):

This zone begins with a sharp increase in Sphagnum spores, accompanied by a drop in Ericaceae levels. Macrofossil examination revealed that the virtually pure Sphagnum peat consists of Sphagnum fuscum and Sphagnum capillaceum, indicating that these two had replaced the Sphagnum fimbriatum type of BBDC - V. Analysis of the ericad spectrum (Fig. 41) reveals that wet (Sphagnum) heathland species with tetrads greater than 30 μ m had replaced those of Ledum type. Inasmuch as the wet heathland species (Andromeda polifolia, Vaccinium oxycoccos, and Vaccinium uliginosum) are very low pollen producers (Ch. 3), their moderate frequencies in zone VI indicate that these species were probably dominant in the vegetation.

A 2 cm-thick charcoal horizon interrupts the Sphagnum peat sequence at

.62 m. Before this fire, Pinus rose to very high levels and the Ledum type dominated the ericad spectrum. This reflects the growth of a shrubby, pyrophilic assemblage of Ledum groenlandicum and Pinus contorta at the site. Close interval sampling (2 cm) in the interval after the fire detected the burn-off of Pinus and Ledum as well as a sudden drop in Sphagnum spores. The sharp drop in Pinus is accompanied by a rise in the level of regional AP pollen types, particularly Alnus. The sudden disappearance of cf. Thuja as well as low overall pollen concentrations may be attributed to the poor preservation within the charcoal layer. After the fire, there is a fast recolonization of Sphagnum and Ericaceae.

Both this fire horizon and the poorly defined fire horizons at about .20-.10 m are followed immediately by Rhynchospora alba seeds and sedge-like remains, indicating a post-fire development similar to that recorded in core CBB.

Desmidiospora fungal spores, characteristic of Sphagnum heathland conditions, are abundant throughout BBDC - VI. Also, Gelasinospora and V.G. 3 fungal microfossils occur in typical association with the two fire horizons.

Subzone BBDC - VIb is delimited from BBDC - VIa by a marked drop in AP except Alnus and Pinus. As in core CBB, this represents the clearing of forests by settlers. In response to clearing there is a sharp increase in Alnus, with concomitant decreases in all coniferous types except pine. The Betula increase can be attributed to the development of a birch woodland in the peripheral bog region, following clearing and draining. The NAP shows increases in Pteridium and Cyperaceae (cf. Rhynchospora), that are probably a direct result of local fires. The increase in grass pollen is from the

establishment of agricultural fields in the vicinity.

Summary

Core BBDC records an intertidal delta-front, or estuarine Scirpus marsh at 4,900 BP. By 4,500 BP, the site had developed into a Carex-Oenanthe freshwater marsh, probably still near the delta-front. A salt marsh phase occurred just before 4,100 BP, produced by cut-off of fresh water influence and subsequent marine transgression. At 4,100 BP a fresh water sedge fen suddenly replaced the saltmarsh, lasting until the 2.5 m level. The fen was replaced by a Ledum groenlandicum shrubland. During this heath shrubland phase, Pinus contorta arrived at the site. In the later stages of the heath phase, Sphagnum appeared and the Sphagnum bog conditions with characteristic ericad species became established. The top 0.20 m shows the reduced conifer levels and sharply increased Alnus frequencies characteristic of Vegetational disturbance produced by the arrival of settlers. Fire horizons preserved in the Sphagnum peats are characterized by the same "Rhynchospora lows" as in core CBB.

Overall, there is the same sequence of development as in CBB including intertidal delta-front marshes, sedge swamps, shrubland and Sphagnum bog. The main differences are the occurrence of a salt marsh phase and the replacement of the Myrica-Spiraea shrubland phase of CBB by a Ledum groenlandicum shrubland phase in BBDC.

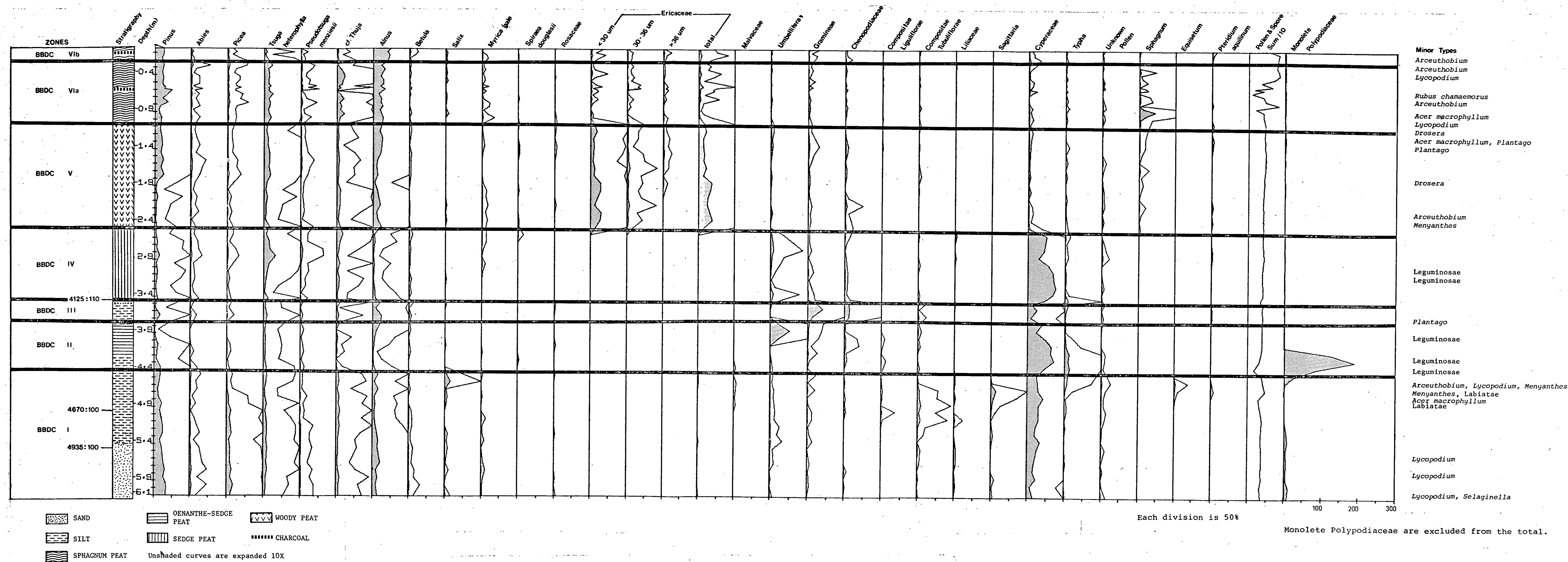


FIGURE 37: POLLEN DIAGRAM FOR CORE BBDC, BURNS BOG, DELTA, BRITISH COLUMBIA.

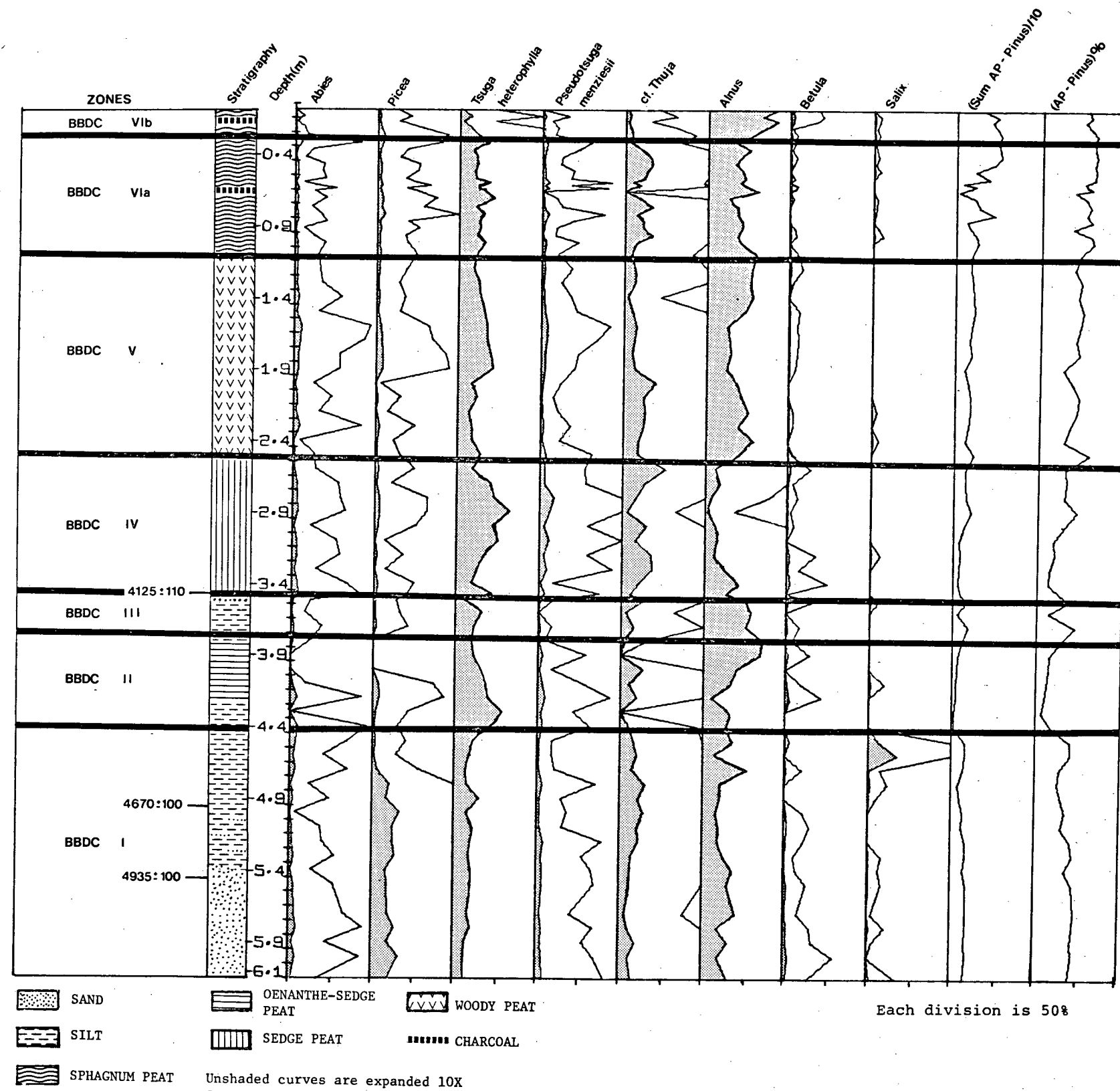


FIGURE 38: ARBOREAL POLLEN DIAGRAM EXCLUDING PINE FOR CORE BBDC, BURNS BOG, DELTA, BRITISH COLUMBIA.

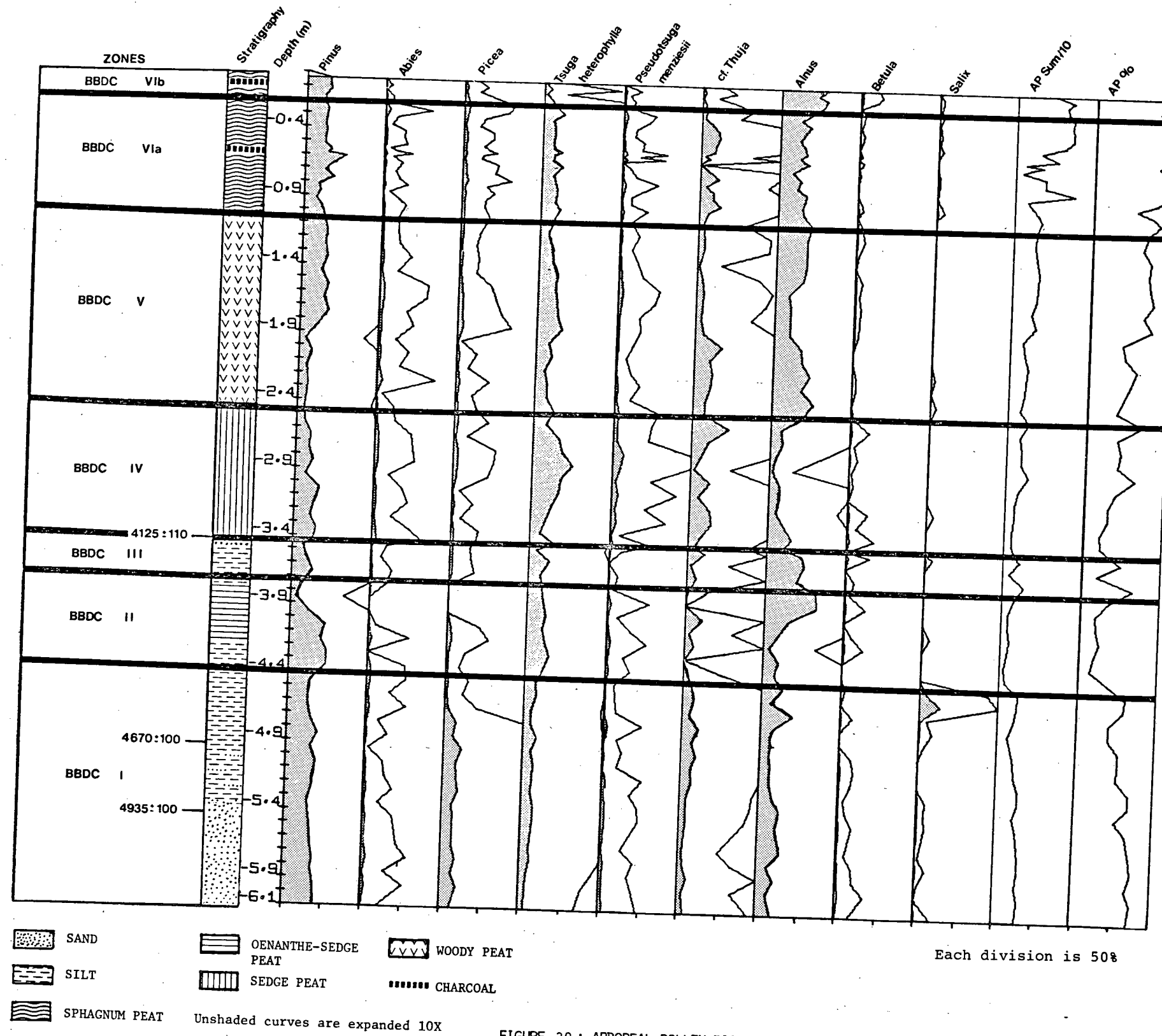


FIGURE 39 : ARBOREAL POLLEN DIAGRAM FOR CORE BBDC, BURNS BOG, DELTA, BRITISH COLUMBIA.

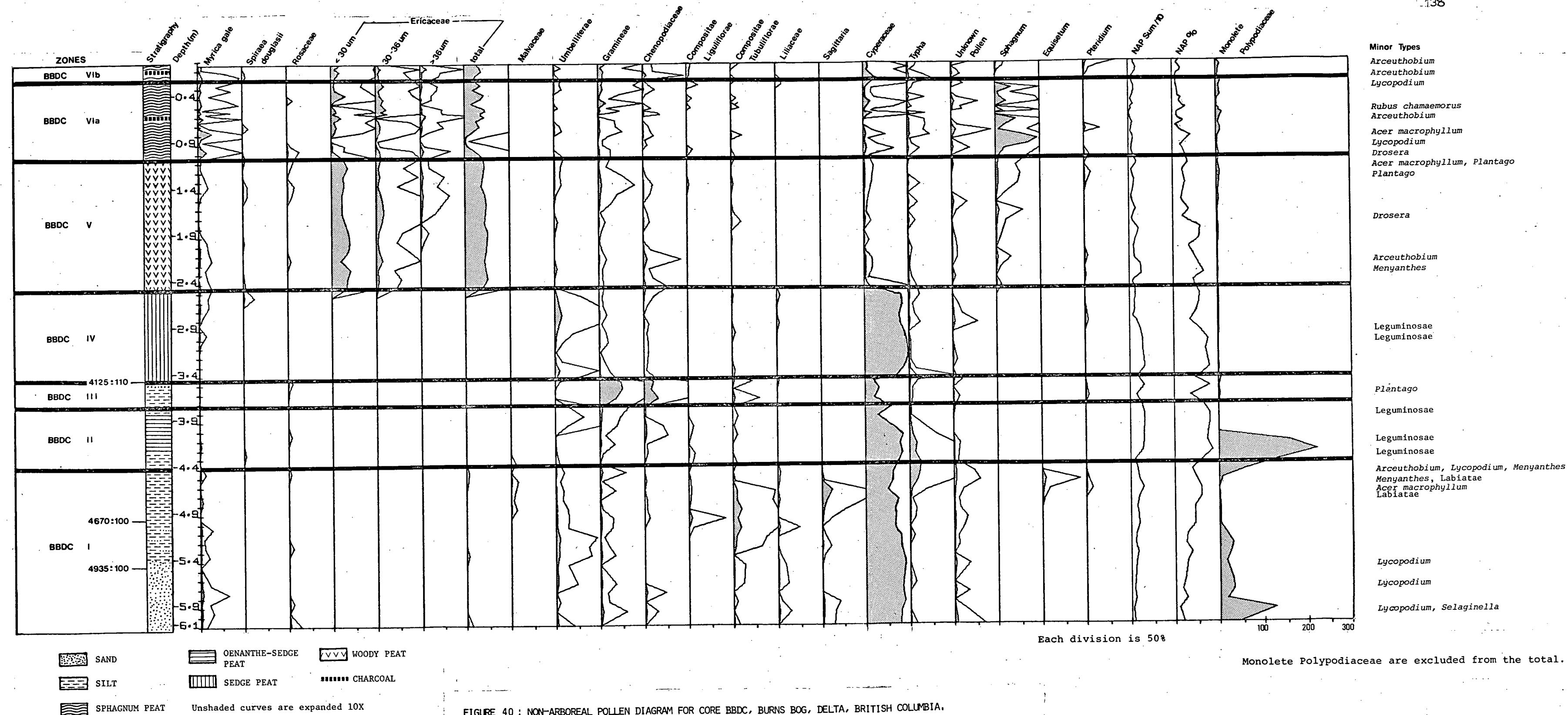


FIGURE 40 : NON-ARBOREAL POLLEN DIAGRAM FOR CORE BBDC, BURNS BOG, DELTA, BRITISH COLUMBIA.

FIGURE 41: SIZE RANGE COMPOSITION OF ERICAD SPECTRUM , CORE BBDC, BURNS BOG, DELTA, B.C.

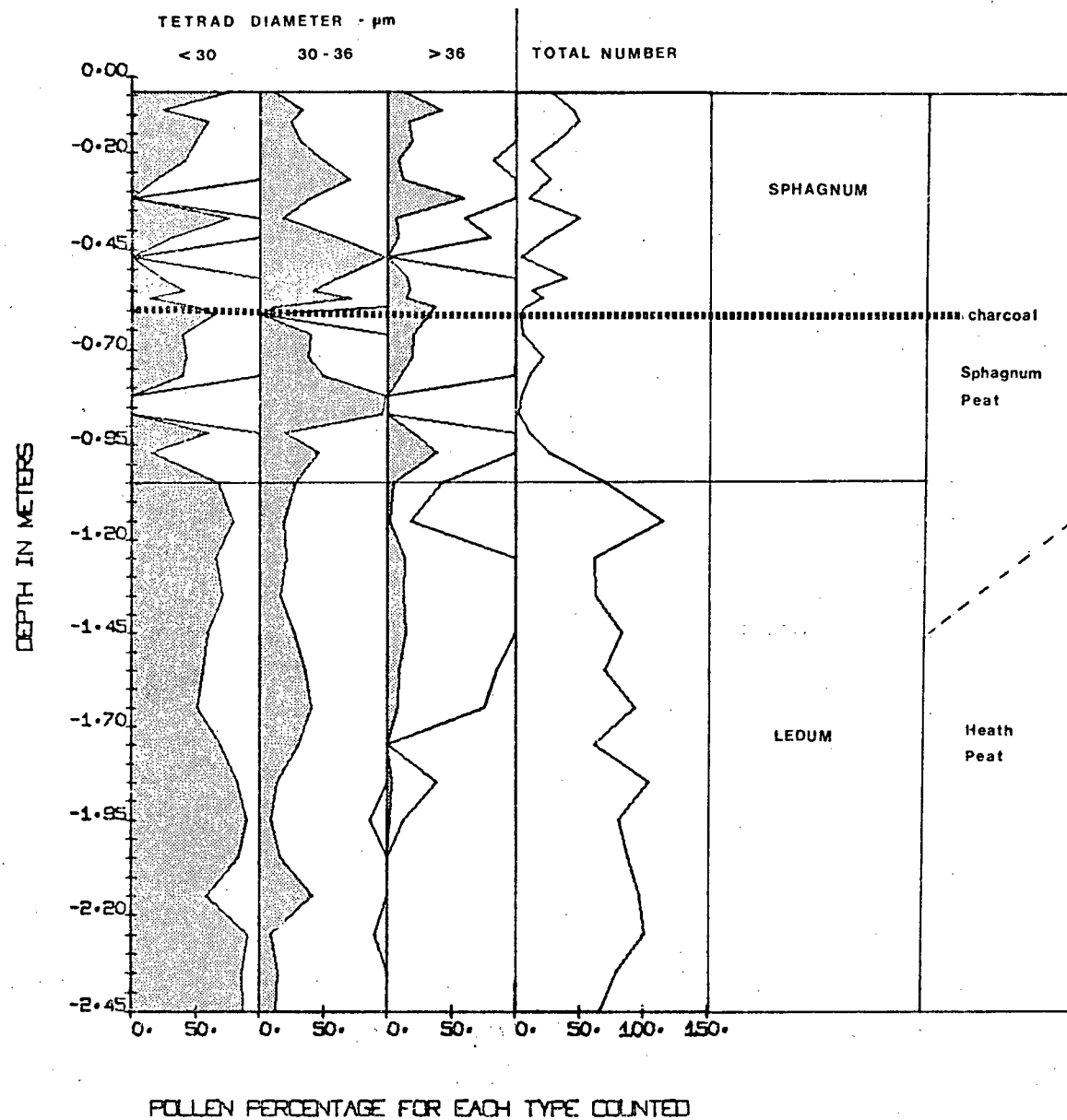
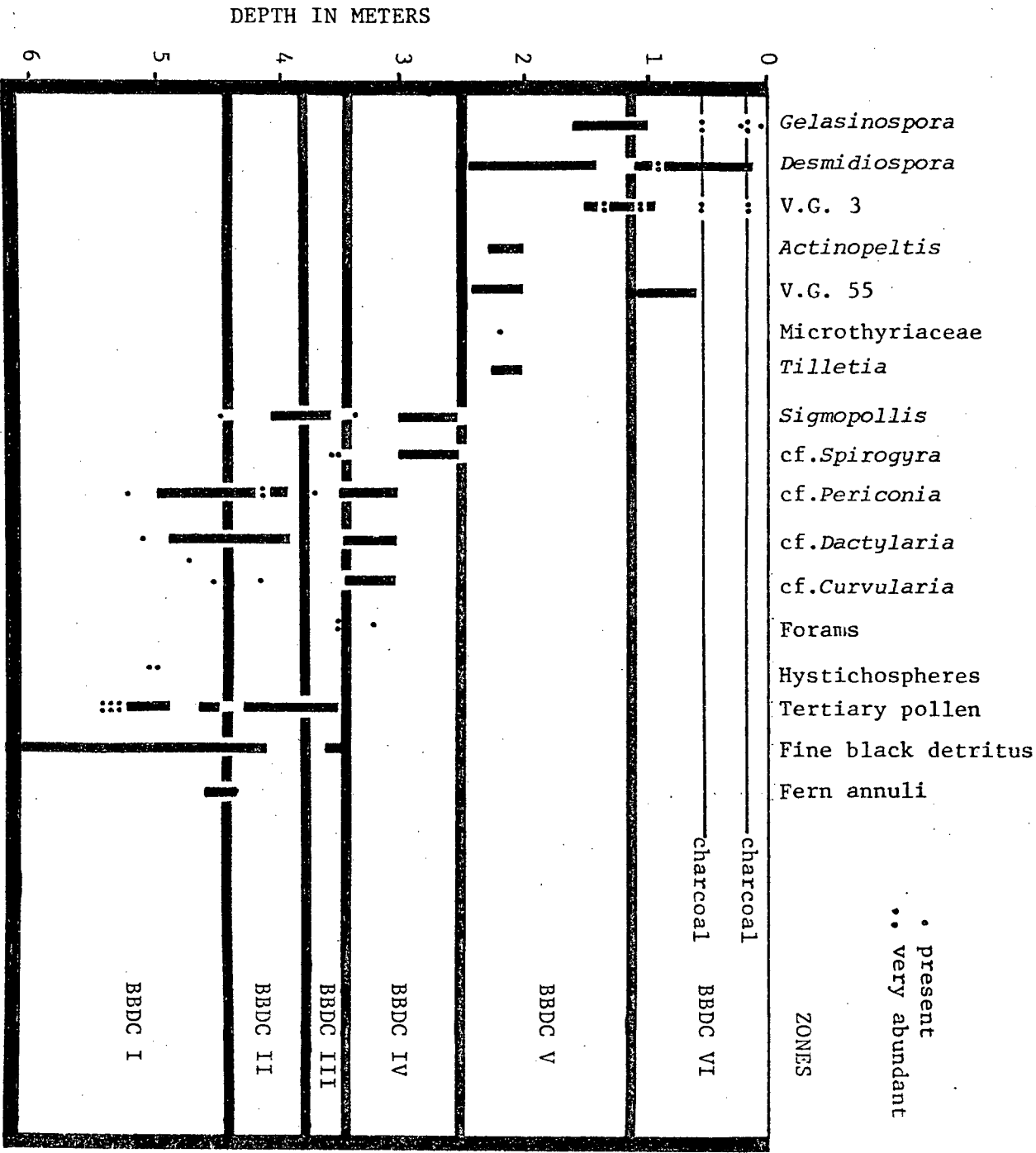


Figure 42: Palynomorph diagram core BBDC.

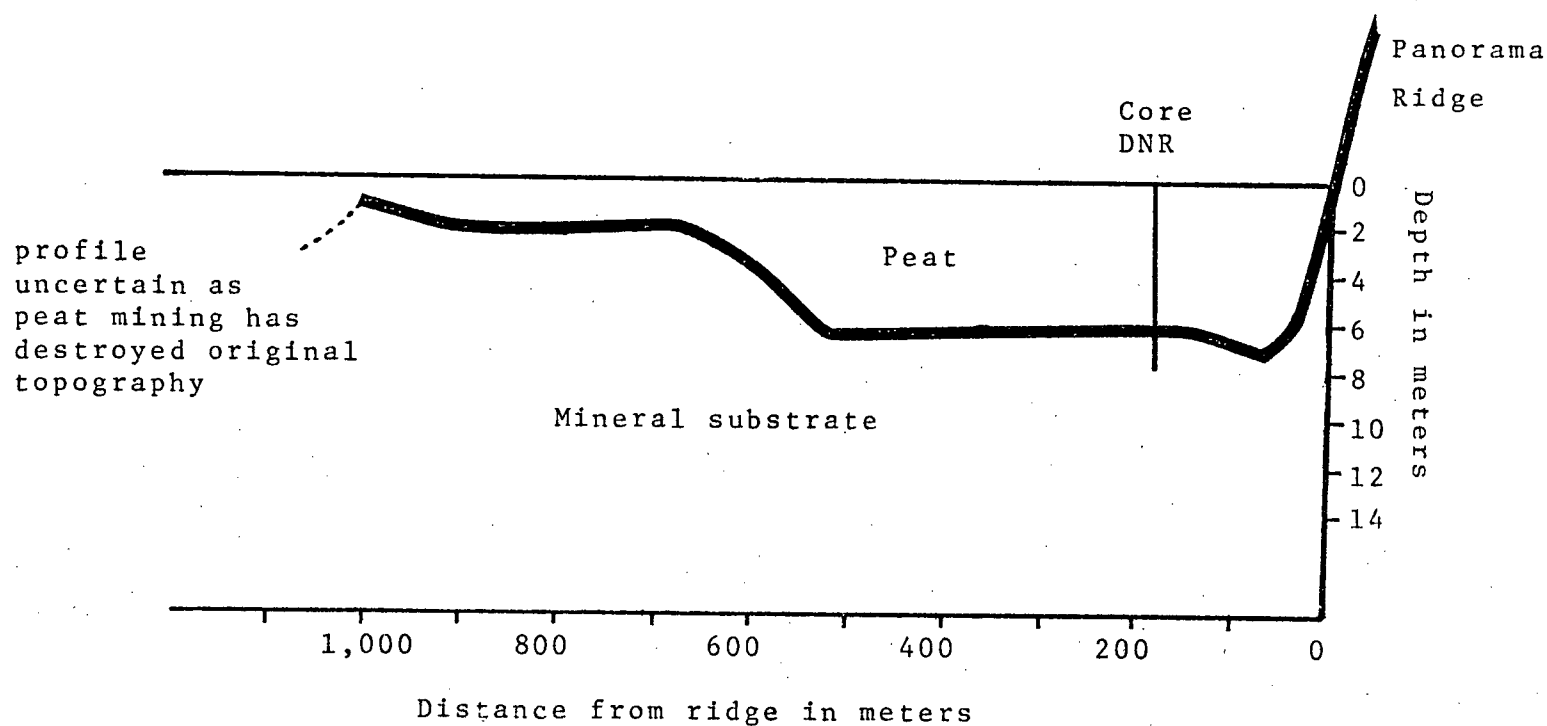


CHAPTER 7: CORE DNR FROM EASTERN BURNS BOGIntroduction

Core DNR was obtained to elucidate the developmental sequence from an area in the eastern section of Burns Bog. The eastern flank of the bog is characterized by patches of Sphagnum heathland vegetation within mixed coniferous woodland. The coring site was located about 400 m west of the foot of Panorama Ridge (Fig. 10). A probe transect from east to west in this area (Fig. 43), carried out to determine peat depths, indicated that this part of the bog has developed in a shallow basin with the steeply sloping eastern edge abutting on the pebble beach deposits of Panorama Ridge. In contrast, the western flank is marked by a low subsurface ridge containing blue-grey silts in the upper part. From the soils map (Luttermerding and Sprout, 1969), the vegetation distribution (Fig. 4), and additional field observations, the mineral ridge appears to form an arc extending from an alluvial fan deposited by the creek running off Panorama Ridge, northward to saline rego gleysol/regosols soils in the northeastern corner of Burns Bog.

The sampling site lies in a transition from Sphagnum heathland to disturbed Mixed Coniferous Woodland. The local trees are Thuja plicata and Tsuga heterophylla. Shrubs at the site include Gaultheria shallon, Kalmia microphylla, Ledum groenlandicum and Myrica gale. There is a Lysichitum hollow (Turesson, 1916) within 2 m of the site and the ground cover consists of a loose carpet of Sphagnum capillaceum. Much of the surrounding area, particularly to the east, is fairly swampy.

Figure 43: Vertical section of eastern Burns Bog(core DNR) showing shallow basin at the foot of Panorama Ridge. Profile follows vegetation sampling transect at eastern end of Burns Bog (see Figure 4, in pocket at back). Surface was assumed to be flat, although up to 1 meter of relief is present



Methods

A total of 8.1 m of deposits was penetrated and sampled for analysis. The top .5 m was obtained from a wall of a pit dug at the site, whereas the remainder of the core was sampled with a Hiller borer. Samples were prepared by the standard procedure outlined in chapter 5. Pollen recovery from the last .6 m was unsatisfactory, and the results are not included. A sedgy silt sample from 6.90-7.00 m was obtained for radiocarbon dating at a site 100 m to the east.

Results and Discussion

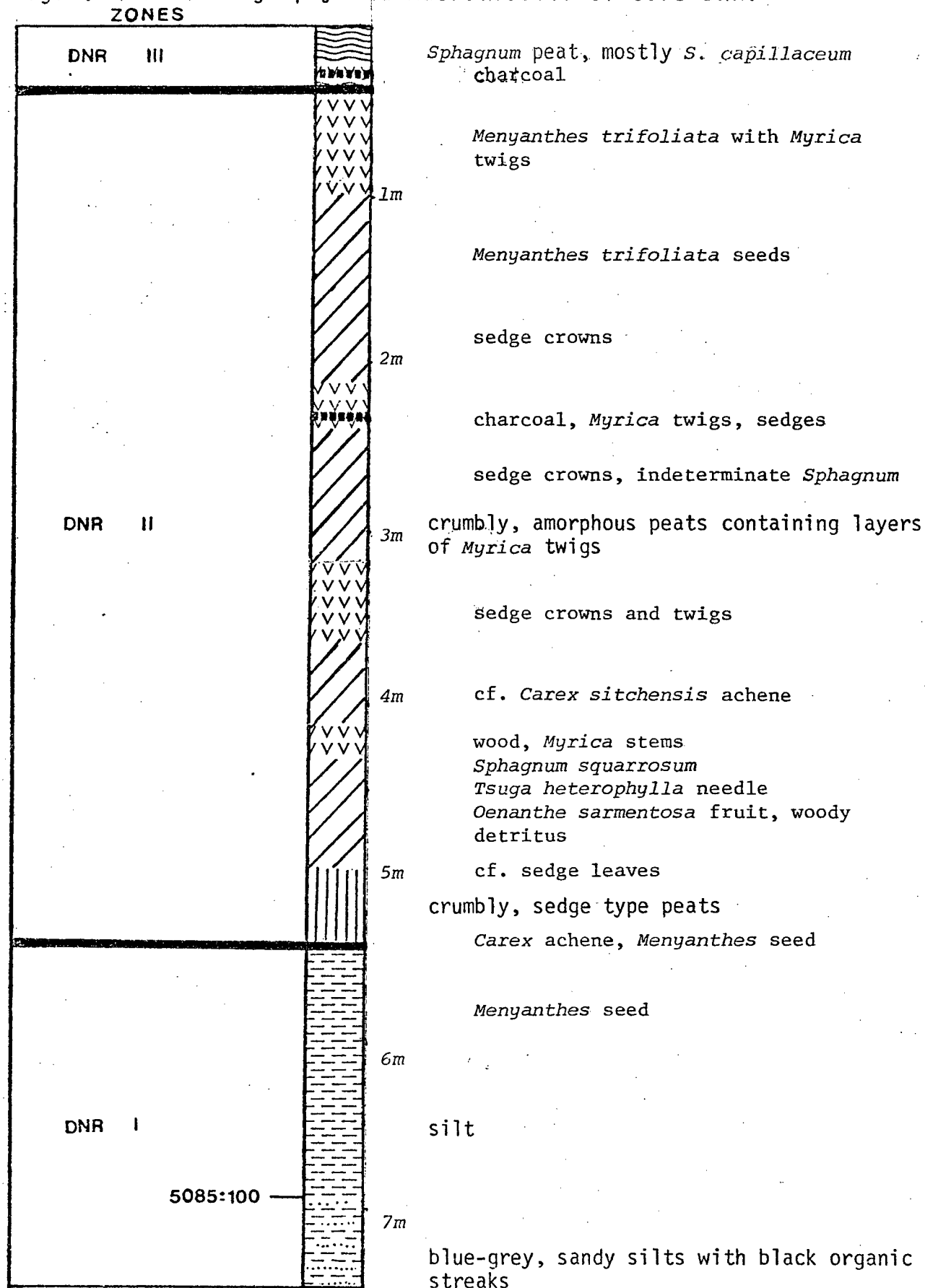
Stratigraphy and Radiocarbon Dating

The stratigraphy of core DNR is summarized in Fig. 44. In general, the basal grey sandy silts appear similar in character to the deposits at the bottom of cores BBDC and CBB. These gradually become more organic in composition, until about the 5.20 m level where the first crumbly sedge peats occur. Organic silts obtained from a depth of 7.00-6.80 m, 100 m to the east of the core site, were dated at $5,085 \pm 100$ radiocarbon years BP (I-9595). There is a long sequence of crumbly, amorphous brown peats (5.20-.40 m), containing sedge remains, wood fragments and Menyanthes seeds. In places, these peats appear to be detrital; possibly they formed in a shallow swamp through which a low stream periodically flowed. The upper .40 m consists of woody Sphagnum peats containing live Lysichitum roots.

Pollen and Macrofossil Zonation

The pollen and microfossil diagrams for core DNR (Fig. 45, complete diagram; Fig. 46, AP; Fig. 47, NAP; Fig. 48, fungal and other microfossils)

Figure 44: Stratigraphy and macrofossils of core DNR.



are included at the end of the chapter, pages

ZONE DNR-I (7.5-5.4 m):

The pollen assemblages of the lower part of zone DNR-I are dominated by arboreal pollen (Fig. 45). Pinus pollen predominates, with relatively high frequencies of Tsuga and Pseudotsuga. Significant levels of Picea are present but are proportionately lower than in similar deposits from zones CBB-I and BBDC-I. There are unusually low values for Alnus, indicating that nearby Panorama Ridge was probably covered by the regionally climax Pseudotsuga forest. Low Alnus levels also suggest that there was very little of the Fraser Delta emergent in the vicinity, as Alnus grows commonly on wet deltaic sites. Near the top of zone DNR-I, the proportion of AP drops, probably as a result of establishment of local stands of emergent aquatic vegetation (cf. CBB-I, BBDC-I) and decreasing deposition of silts that normally contain a high AP load.

The NAP is dominated by Cyperaceae pollen as in the other two cores. In the upper part of the zone, at least, the high cyperaceous frequencies represent local stands of Carex, judging from the occurrence of Carex achenes. The presence of pollen, spores and macrofossils of other emergent aquatics such as Typha latifolia, Malvaceae, Equisetum sp. and Menyanthes trifoliata, along with Carex, indicates an emergent land surface.

The non-vascular plant microfossil assemblage (Fig. 48), characterized by abundant cf. Periconia conidia, traces of cf. Dactylaria conidia, and forams, resembles that of zones CBB - I and BBDC - I. Similarly, there are large numbers of reworked Tertiary pollen grains, together with a high concentration of fine black detritus.

In summary, the history of DNR - I appears to be essentially the same as the equivalent intervals of both CBB - 1 and BBDC - 1, representing an emergent intertidal delta-front, brackish to fresh water environment.

ZONE DNR-II (5.40-0.40 m):

In keeping with zonation in cores CBB and BBDC, the boundary between DNR - I and DNR - II has been placed at the Pinus-Picea decline which occurs at the silt to peat transition. Throughout this long interval (DNR - II), Tsuga and Pseudotsuga remain the main AP types (Fig. 46). Because these trees maintain more or less constant frequencies, it seems that the forest on Panorama Ridge remained essentially unchanged. Alnus initially rises to high levels at 4.00 m and probably indicates colonization of newly-emergent deltaic environments near the site. As the soils matured and swamps developed, Picea seems to have taken over. Alnus rubra does not seem to grow presently on deep organic deposits below Panorama Ridge (see Ch. 2), whereas Picea sitchensis thrives on these sites. Hence, the increase of Picea may also indicate that sufficient organic material had accumulated in the local swamp (2 m) at site DNR to exclude alder. Thuja, which also grows well in the present swampy sites, reaches its best representation in the lower part of zone DNR - II, but curiously fades out near the top. This may be a preservational phenomenon. At the 2.00 m level there is a marked increase in Pinus pollen to 50% AP, likely attributable to two factors: Pinus contorta could have colonized local drier organic substrates, as it does now; or pine may have invaded the mature surface of the adjacent raised bog at that time, with pollen dispersal by wind easterly into the swampy areas.

The NAP diagram (Fig. 47) indicates that there may have been two local vegetational phases. The first is characterized by grasses and sedges (5.40-4.00 m). The second phase (4.00-0.40 m) contains shrubs such as Myrica and Spiraea, together with Lysichitum americanum and Menyanthes trifoliata. These latter two species appear to alternate, suggesting there may have been shallow ponds alternating with wet Myrica-Spiraea thickets.

The NAP diagram for zone DNR - II indicates that grasses (up to 60% NAP) probably grew locally, along with cf. Athyrium filix-femina, whose spores (monolete Polypodiaceae) and sporangia occur in great numbers. Attempts were made to differentiate monocot leaf macrofossils in the sediments to confirm that grasses did indeed grow at the site. Although some of the epidermal patterns were grass-like, it was impossible to differentiate them definitively from Carex epidermal patterns. The peat corresponding to the grass peak is of a crumbly nature, very much like that forming in wet grasslands today. Also, many of the grass grains are folded and crumpled, a feature characteristic of wet grassland deposits. Finally, the apparently stable upland vegetation of Panorama Ridge (based on constant Pseudotsuga levels and high, presumably lowland-derived Alnus pollen levels) suggest that there probably was not any source of grass pollen external to the site. Cyperaceae, probably Carex sp. and some Typha latifolia occurred with the grasses. Also, an Oenanthe sarmentosa seed was found at 5.10 m. This wetland umbellifer grows today near site DNR, favouring habitats that are periodically submerged (e.g. swamp hollows). Oenanthe pollen occurs sparsely throughout zone DNR - II.

Between 4.50 and 4.00 m, the NAP gradually changes with an influx of Lysichitum americanum pollen and pollen from Myrica gale and Spiraea

douglasii. This change is also shown by the presence of twigs, some of which belong to Myrica. The occurrence of a fruit of Carex sitchensis indicates that this swamp sedge was also part of the vegetation.

Although there is little pollen of Menyanthes preserved in DNR - II (cf. Ch. 4), high numbers of Menyanthes seeds in the peat suggest that the upper 2.20 m was deposited in a shallow Menyanthes-filled depression. A period of Myrica shrubland interrupted the Menyanthes stage at 2.40 m, pointing to a brief interval of emergence. There is also a prominent layer of charcoal at this same horizon, indicating a substantial fire during the brief Myrica phase.

Large numbers of fern annuli occur throughout DNR - II, confirming in situ growth of a fern, probably Athyrium filix-femina, a common swamp species of the region.

A few fungal spores and algal microfossils were also recovered from DNR - II. These include cf. Curvularia fungal spores, Spirogyra sp. zygospores (sensu Van Geel, 1976b) and spiny Sigmopollis types. Algal zygospore production suggests again that periodic submersion in shallow water was a feature of this site (Van Geel, 1976b).

In short, the extended zone DNR - II represents a fresh water swamp phase, with alternating periods of emergence and submergence.

DNR-III (0.40-0 m):

Sphagnum peats and Sphagnum spores indicate the very recent advent of bog conditions near the boundary of zones DNR - II and DNR-III. At the beginning of the zone, the AP is unchanged from DNR - II. Soon after, Alnus rises sharply, whereas the conifer pollen frequencies drop. There are also increases in Pteridium and Spiraea frequencies during this time.

These events signal the arrival of European man, together with logging of parts of the local swamp forest. The occurrence of Epilobium pollen confirms local clearing and reflects the fire indicated by the charcoal horizon at 0.30 m. The high Lysichitum levels are produced by nearby plants. The fungal spores and rhizopods occurring in DNR ~ III are those characteristic of Sphagnum bog habitats.

It is difficult to determine whether Sphagnum bog conditions arose as a result of disturbance of the area, or as a consequence of natural successional events. The vegetation map (Fig. 4) shows that bog conditions may have spread from the north, perhaps derived from the central cupola of Burns Bog to the west. If this were the case, then the spread of Sphagnum had probably begun long before the arrival of European man, and only recently has reached this part of Burns Bog. Both to the east and to the west of site DNR, in mixed coniferous forest, there appears to be no evidence for Sphagnum peats near the surface. At present, site DNR occurs in the transition between swamp and bog vegetation. This suggests that unless there are additional further disturbances, the boggy portion of the eastern bog will continue expanding.

Summary

Core DNR records the vegetation of a shallow basin at the foot of Panorama Ridge, separated from the rest of Burns Bog by a subsurface mineral ridge. Succession began around 5,000 BP with emergent aquatic vegetation dominated by Cyperaceae. As silt deposition tapered off at the 5.40 m level, a sedge-grass marsh became established. This was followed by a

swampy Myrica-Spiraea shrubland containing Lysichitum. At the same time Alnus appeared to colonize lowland mineral sites, being subsequently replaced by Picea. Near the upper end of the swamp/marsh interval, Menyanthes trifoliata grew abundantly at the site. Very recently (.40 m) the current Sphagnum bog conditions became established. Charcoal horizons and Epilobium pollen accompanied by decreased conifer frequencies and increased Alnus reflect local fires and logging activity.

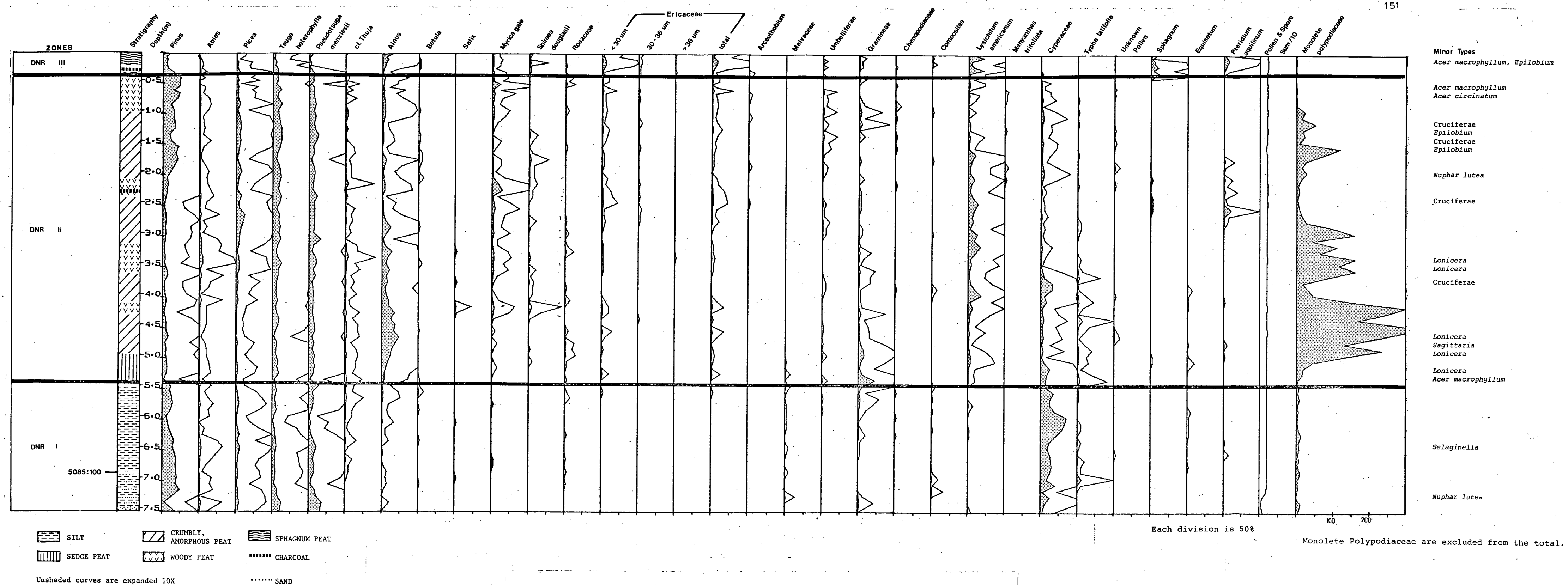
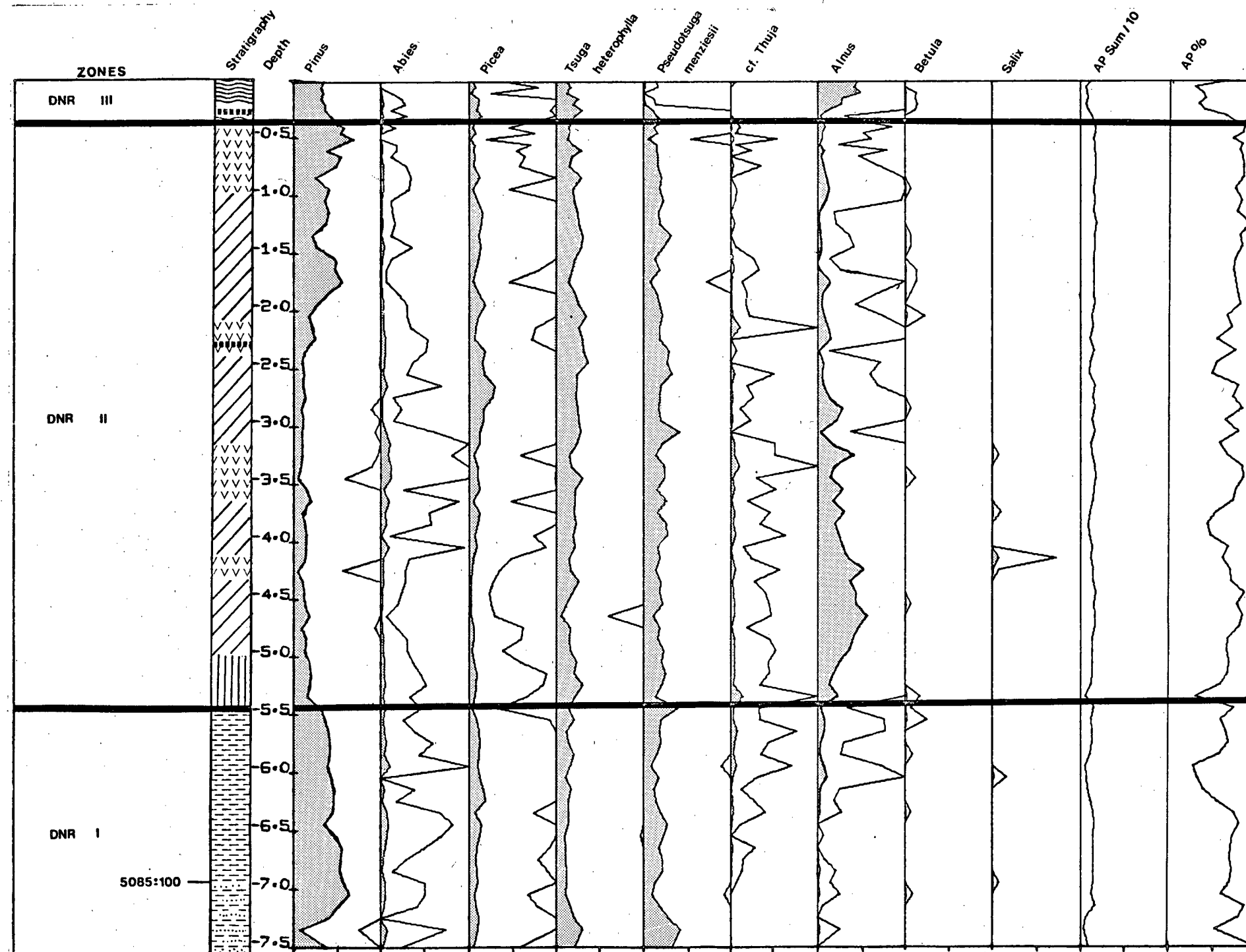


FIGURE 45 : POLLEN DIAGRAM FOR CORE DNR, BURNS BOG, DELTA, BRITISH COLUMBIA.



SILT
 CRUMBLY, AMORPHOUS PEAT
 SPHAGNUM PEAT
 SEDGE PEAT
 WOODY PEAT
 CHARCOAL
 SAND

Unshaded curves are expanded 10X

FIGURE 46: ARBOREAL POLLEN DIAGRAM FOR CORE DNR, BURNS BOG, DELTA, BRITISH COLUMBIA.

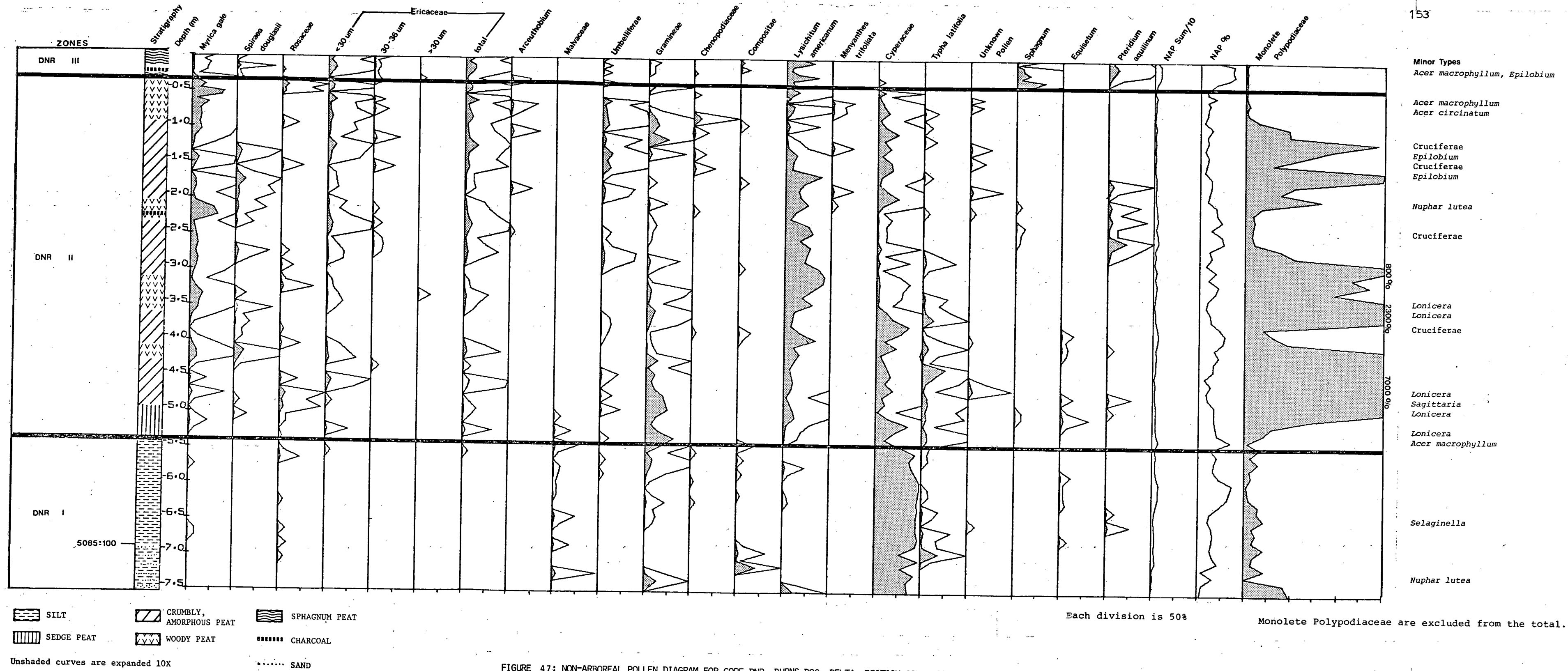
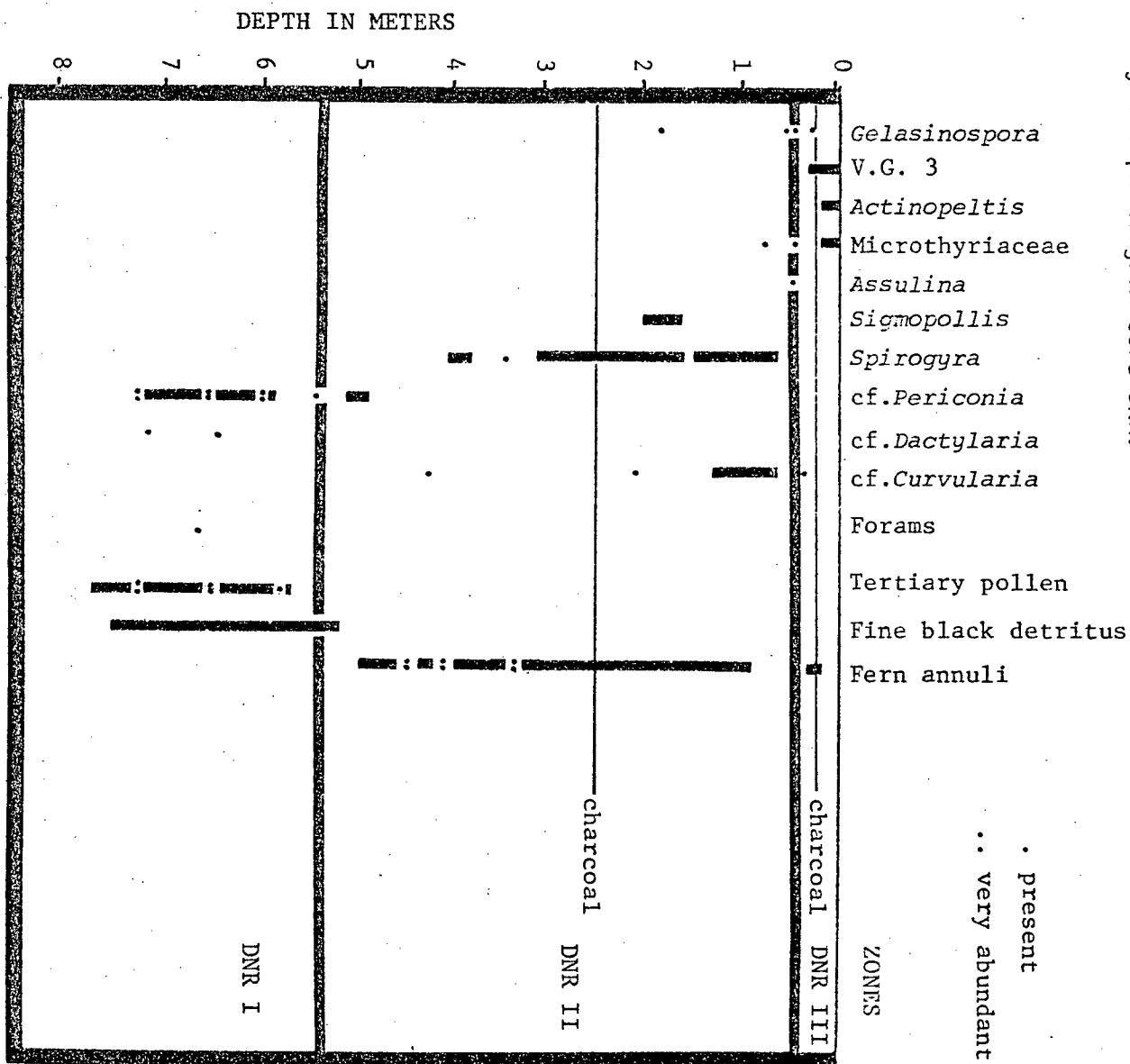


FIGURE 47: NON-ARBOREAL POLLEN DIAGRAM FOR CORE DNR, BURNS BOG, DELTA, BRITISH COLUMBIA.

Figure 48: Palynomorph diagram core DNR.



CHAPTER 8: SYNTHESIS, DISCUSSION AND SUMMARY

INTRODUCTION

This chapter synthesizes the information obtained from the three cores (CBB, BBDC, DNR) into a general outline of the origin of Burns Bog starting with the freshly exposed deltaic surface and its development through sedge swamp and shrub phases to the current raised Sphagnum bog. This developmental sequence is compared to what is known about other raised bogs in the area and a model is proposed for raised bog development on the Fraser Lowland. The Burns Bog sequence is compared with the origin and growth of raised bogs in British Columbia, and deltaic raised bogs elsewhere. The paleoecology of Burns Bog is discussed in terms of the evolution of the southern Fraser Delta, particularly in terms of sea level and river channel changes. The potential applications of the results of this study are discussed and the major contributions of the thesis are summarized.

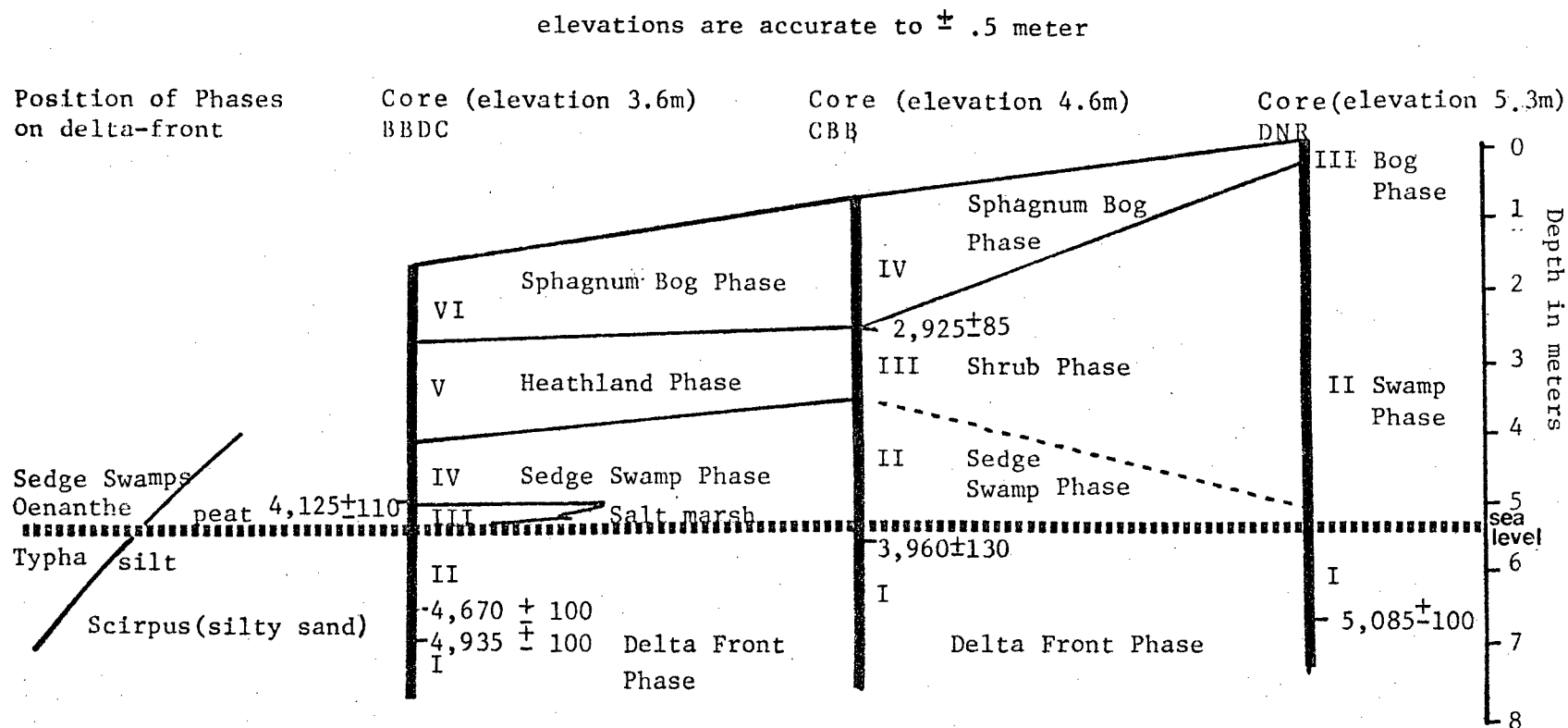
SYNTHESIS

The Origin and Growth of Burns Bog

A general sequence of events in the development of Burns Bog can be synthesized by comparing results and correlating zones of the three cores, along with observations on bog stratigraphy from other exposed sections (Fig. 49).

Delta-Front Phase: At about 5,000 years BP, well after the current regional forests had become established (Mathewes, 1973), pioneering vegetation

Figure 49: Correlation of the three cores from Burns Bog.



probably consisting of Scirpus spp. and other emergent aquatics began to colonize the brackish, silty sands of the intertidal zone of the prograding delta-front. The change from the sand-dominated submerged environment to the silt/peat-dominated sub-aerial environment seems to have been nearly isochronous at the three sites as shown by radiocarbon dates in core BBDC and DNR, and an extrapolated date for core CBB, based on a sedimentation rate of .17 cm per year.

Subsequently, as organic sedimentation replaced silt deposition, there was a distinct change to sedge-dominated swamps. In core CBB, the transition occurred immediately after $3,960 \pm 130$ BP. In core BBDC, following the development of an Oenanthe sarmentosa wetland, a marine transgression temporarily interrupted the succession to sedge swamps by interposing a salt marsh phase at $4,125 \pm 110$ years BP. The sedge swamp phase in core DNR has not been designated as a zone; rather it is considered as a short interval of sedge-grass dominance following the emergent delta-front period. In all three cores, the switch to predominantly organic accumulation happened at a depth very close to present sea level (geodetic datum). At this point in development, there was periodic weak flooding, indicated by traces of silt. The area, during the sedge-swamp period, was probably a low, flat wetland, covered with many shallow pools resulting from flat topography and poor drainage. Numerous observations of peat diggings, drainage ditches, and Hiller borings by Rigg and Richardson (1938), indicate that the sedge-swamp deposits underlie much of the bog.

Shrub and Heathland Phase: The sedge-swamp phase is followed by the development of shrubby vegetation in cores CBB (Myrica-Spiraea) and BBDC (Ledum). This shrub phase, characterized by the accumulation of woody peat, seems to have been widespread throughout the bog (Rigg and Richardson, 1938). In

core DNR, a swampy Myrica-Spiraea shrubland appears to have developed; swamp conditions are indicated by the high pollen levels of Lysichitum americanum.

Sphagnum Bog Phase: The shrubby phase marks the first appearance of Sphagnum leaves (Sphagnum fimbriatum type) with a few Sphagnum spores. In both cores CBB and BBDC, the appearance of this moss is followed by a Sphagnum bog phase, apparently much like the present vegetation of Burns Bog. This transition occurs at about the same horizon above sea level in both cores. It is traceable in drainage ditches and peat cuttings, and follows a more or less horizontal plane across the bog. Comparison of surface elevations with determinations of Sphagnum peat depth (Anrep, 1928) further supports this conclusion. A radiocarbon date on this transition from shrubs to Sphagnum in core CBB indicates that raised bog conditions developed at this site at about $2,925 \pm 85$ BP. Sphagnum bog conditions at core site DNR did not arise until very recently, following an extended shrubby to open swamp period, probably maintained by run-off from Panorama Ridge. The Sphagnum mosses presumably spread from the extensive areas of Sphagnum in Burns Bog to the west.

The advent of Sphagnum bog conditions in Burns Bog is accompanied by a change in the ericad spectrum from an association of Ledum with some Empetrum, to one consisting most likely of Andromeda polifolia, Kalmia microphylla, Vaccinium oxycoccos and Vaccinium uliginosum. Pinus contorta appears to have arrived before the full establishment of the Sphagnum heathland vegetation.

Fire Horizons: The Sphagnum peats contain a number of distinct charcoal horizons. These are particularly abundant in the upper few centimeters.

There is a clearly recognizable effect from these fires expressed in both the pollen and macrofossil record. Pines appear to be affected in two ways; where pine seemed to grow well (e.g. .62 m level core BBDC) fire resulted in a sharp decrease of this species with only a slight recovery later. Where it grew relatively poorly (1.25 m level, core CBB), burning produced a sharp increase, with eventual return to pre-fire levels. This increase probably occurred because Sphagnum was destroyed by the fire, permitting vigorous growth of pine seedlings in contrast to the pre-fire situation. To verify this interpretation more fire horizons need to be examined in detail. The major fires in the Sphagnum phase appear to have totally destroyed the ground-cover vegetation. All the major fire horizons in cores BBDC and CBB are followed by the sudden disappearance of Sphagnum and pronounced reductions in Ericaceae. Ericaceae recovered quickly, whereas Sphagnum (spores) showed a slower rate of recolonizing. Fungal microfossils characteristic of humification became quite abundant in the fire horizons, indicating temporarily stagnant conditions prior to re-establishment of Sphagnum. During the post-fire period, peat accumulated slowly, consisting mainly of heath litter, fungal hyphae and Rhynchospora alba remains. These burned areas became wet depressions, while surrounding unburned hollows took over as sites of active Sphagnum growth. Eventually, these unburned depressions became extensive hummock-mat complexes that contributed to the growth of the raised bog. With time, Sphagnum re-occupied the burned depressions, and converted them to active accumulation sites. This process was accelerated if new fires razed the area while these depressions were still wet. A model of the fire induced hummock-hollow syndrome is shown in Ch. 2 (Fig. 7).

An interesting parallel to the fire-induced formation of depressions ("Rhynchospora lows") in Burns Bog occurs in the Okefenokee Swamp of Georgia. Studies of peat petrography and paleoecology by Cohen (1974) indicate that major fires often converted cypress (Taxodium)-dominated swamps to water lily-dominated marshes and that this effect has been instrumental in modifying swamp vegetation. This sort of fire phenomenon, affecting peat deposits and peatland vegetation, may be more widespread, but as far as is known by the author, it has not been previously recognized in Sphagnum bogs.

Burns Bog Development in Relation to Other Raised Bogs
in the Fraser River Delta

There is one core from the Fraser Lowland to which the developmental sequence of Burns Bog can be compared. Hansen (1940) obtained a 5 m core from Lulu Island Bog north of Burns Bog with the purpose of determining the regional forest history. Although his sample interval was .5 m, the sequence obtained seems to parallel that of Burns Bog. In the Lulu Island core, Pinus and Picea are the dominant pollen types in the lower, sandy/silty deposits. In peat at 2.5 m, Typha tetrads predominate and Cyperaceae pollen appears in significant quantities, increasing to very high frequencies at 2.0 m. Some chenopod and grass grains also indicate a trace of salt marsh vegetation. The sedge period is succeeded by fibrous peat, containing abundant Ericaceae, very similar to corresponding levels in cores CBB and BBDC. Unfortunately no note was made by Hansen of Sphagnum spores, although Sphagnum was reported in the surface vegetation.

A General Model for Raised Bog Development in the Fraser Delta (Fig. 50)

A model can be constructed for raised bog development in the Fraser River Delta based on results from Burns Bog, Lulu Island Bog, and on observations on Pitt Lake Bog vegetation (Barnard, 1975).

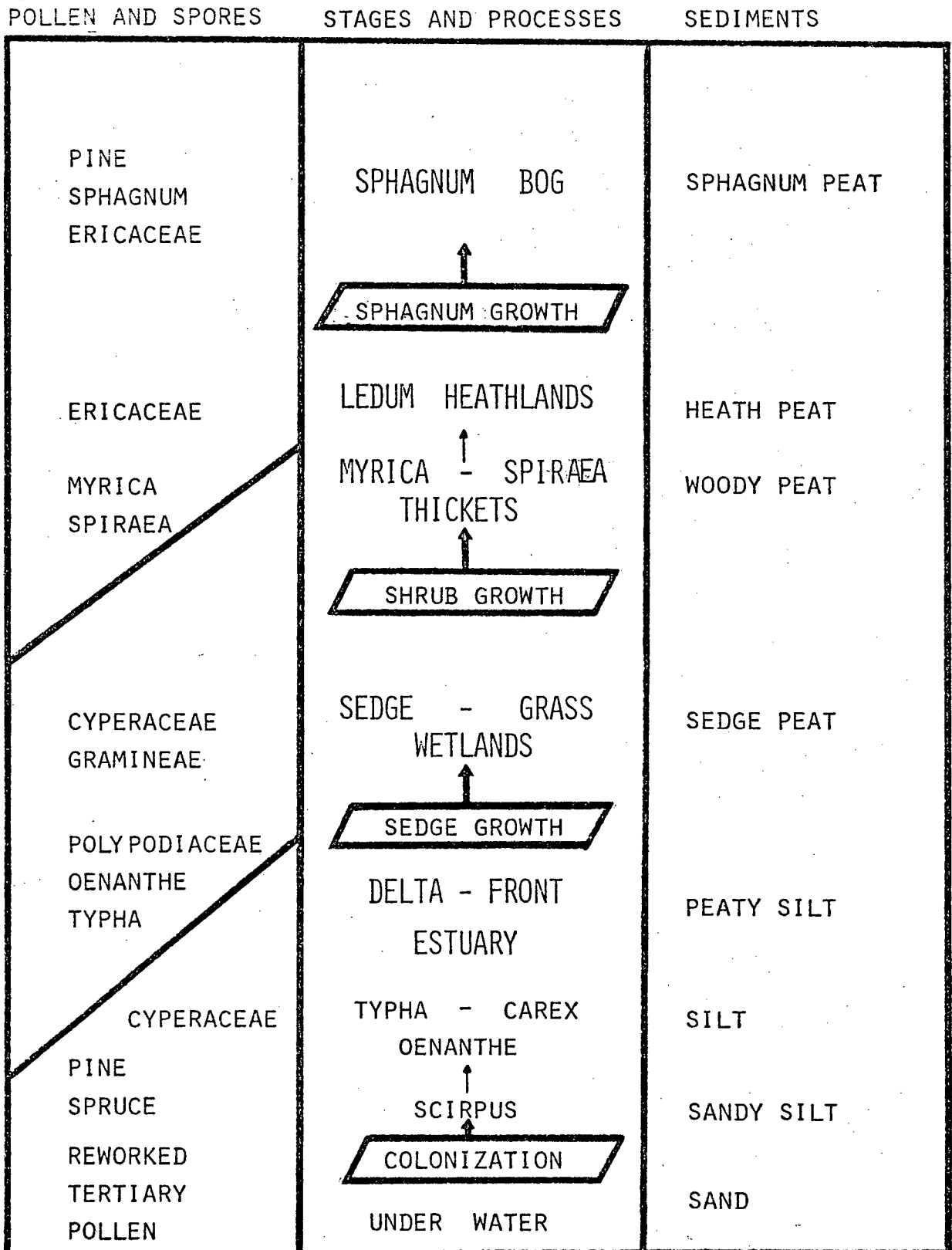
Colonization Phase: The first stage, "colonization", is equivalent to that preserved in the basal sediments of the three cores in this study, and occurs when prograding deltaic surfaces are colonized by aquatics, e.g. Scirpus and Carex. It is characterized by sandy silts grading to peaty silts.

Sedge-Grass Phase: For further accumulation above the local water table, the conditions necessary for a peat-forming template must be met (Moore and Bellamy, 1973). Enough water must be retained at the site so that organic decomposition is retarded. In the Fraser Delta, periodic flooding and local precipitation combined with poor lowland drainage provide suitable moisture regimes so that peat accumulation can occur. Traces of silt are added by periodic flooding.

Under these conditions sedges thrive, along with wetland grasses, producing the organic material responsible for peat formation. The sedge stage is preserved in sediments throughout Burns Bog, as well as in Lulu Island Bog (Hansen, 1940). A modern analog of this stage occurs in the wetlands south of Pitt Lake (Barnard, 1975).

Shrub Phase: Shrub development follows the accumulation of sedge peats, with Myrica, Spiraea and later Ledum, replacing sedges and grasses. The change from sedge-grass wetlands to shrubs may result from; a) organic acid accumulation, b) decreased nutrient availability from the mineral

Figure 50: Proposed model for raised bog development in the Fraser Delta, B.C.



horizon buried under the sedge peats, c) increased elevation and drying as a result of sedge peat accumulation. Myrica is known to be a proficient nitrogen fixer under anaerobic acidic conditions (Moore and Bellamy, 1973; p. 127). Spiraea must also be adapted to these conditions, as it is the dominant shrub of poorly drained wetlands of southwestern British Columbia and often grows at the edges of bogs (Osvald, 1933; Rigg and Richardson, 1938).

With further increases in elevation from peat accumulation, and decreases in the water-holding capacity of the coarse, woody peat, desiccation of the surface is increased. This leads to accelerated decomposition, and presumably to increased acidity in the upper peat layers. Eventually the substrate becomes suitable for the growth of those Sphagnum species (e.g. S. fimbriatum) tolerant of somewhat drier conditions.

Sphagnum Bog Phase: Once Sphagnum mosses become established, the storage capacity of the site increases markedly, reflecting the high water-retention ability of the hyaline cells of these mosses (Rigg, 1940). The hyaline cells, through capillary action (Moore and Bellamy, 1973), delay the outflow of precipitation, the main source of water for the system. Sphagnum may also decrease evaporation, acting as a seal over the surface. The net effect is an increase in the storage capacity of the peat mass and additional peat accumulation.

The disappearance of Spiraea and Myrica is associated with Sphagnum development. Sphagnum has a high exchange capacity for cations (Clymo, 1963) and probably deprives Myrica and Spiraea of nutrients. Sphagnum growth eventually also restricts the growth of Ledum resulting in the development of typical raised bog vegetation.

Although the order of progression of Sphagnum species in bog development has not yet been established for the Fraser Delta, it appears that Sphagnum capillaceum plays an important role in the process. For example, at Pitt Lake Bog, S. capillaceum is the main builder of hummocks within the Ledum-dominated area. In southern Burns Bog, areas regenerating after either fire or clearing, are actively being covered by coalescing hummocks and mats of Sphagnum capillaceum. Sphagnum papillosum hummocks also occur in these regenerating areas, but in fewer numbers. Once S. capillaceum becomes established, presumably there is a progression towards the development of a classic raised Sphagnum bog.

The general model for raised bog development presented here is not intended to represent the sequence to be found at every locality in every bog in the Fraser River Delta, nor can all the phases of the sequence be expected to occur in every core. The shrub phase varies in duration and composition as illustrated by core BBDC where Ledum dominates and core CBB where Myrica and Spiraea dominate. However, it seems, that in general, raised bog development on the Fraser River Delta involves a sedge stage, followed by some sort of shrub stage, eventually leading to the Sphagnum stage. Additional cores from other bogs need to be analyzed to confirm and refine this model.

DISCUSSION

Comparison of Fraser River Delta Raised Bog Development with Other Raised Bog Sequences

Rigg (1925) discussed Sphagnum bog development of the North Pacific Coast of North America on the basis of a field study of 78 bogs. Although

he did not use palynologic techniques he was able to suggest that in many bogs the development sequence was from sedge to shrub to Sphagnum bog phases. He concluded that in most cases Sphagnum bog encroached on swamp environments (shrubs) and thus that "the bog association commonly follows a swamp association". These conclusions are clearly confirmed for the bogs of the Fraser River Delta by this study.

Heusser (1955, 1960) described a number of cores from various bogs in the Queen Charlotte Islands, Vancouver Island and the west coast of British Columbia. Some of these appear to have developed without a limnic basal peat, and to have produced considerable depths of peat, and so appear to be raised bogs. Direct comparison of these to Burns Bog is difficult because Heusser's main objective was to obtain paleoclimatic information. However, it appears that sedge peats always form the basal organic layer as in Burns Bog. Ligneous peats follow, although the nature of these is not always clear, and they may have been produced mainly by trees instead of shrubs. Heusser's pollen profiles do not indicate clearly the presence of shrub-dominated horizons. Sphagnum peats and high numbers of Sphagnum spores occur toward the tops of most of these sequences. Heusser ascribed most of these local vegetation/peat changes to climatic factors. From the results in Burns Bog, it is probable that at least some of the changes are the result of natural successional phases in bog development. For example, some of the climatic reasons given by Heusser (1960; p. 128-130) for appearances, disappearances and frequency changes in species might be accounted for better by successional changes.

Auer (1930) carried out an extensive investigation of peat bogs in southeastern Canada. In the case of raised bogs, particularly the maritime

ones of eastern Canada, he found that Carex peat rested on mineral soil, with tree stumps seldom found in the basal Carex layers. He concluded that paludification of the land into peat bogs was chiefly the result of the spread of Carex associations, and that Sphagnum peats developed subsequently on this substrate. In contrast to Burns Bog, none of the raised bog profiles of the east coast show a definite shrub stage, although Auer mentions the growth of dwarf shrub plant assemblages on Carex peat.

Elsewhere in the world, only one similar deltaic or estuarine raised bog has been found for comparison. This is Shopwick Heath, Somerset, England, where Godwin (1975) describes a raised bog that developed on estuarine clays. The sequence of development is: Phragmites-Cladium (sedge-type peat), followed by a thin layer of woody peat (Betula fen wood); a Calluna-Sphagnum stage and finally Molinia-Sphagnum peats. Although the species composition is very different from that of Burns Bog, there is a marked successional similarity between this sequence and that proposed for the Fraser River Delta. In both, emergence is followed by open sedge fens, which presumably give suitable conditions for the eventual advent of more acidophilous species typical of raised bogs.

In general it seems that the Burns Bog sequence bears some similarity to that of other raised bogs, most particularly on the west coast of North America. The basal sedge phase seems to be especially characteristic, although the development of a shrub phase is apparently not shared with other bogs.

The Role of the Raised Bog in Fraser River Delta Evolution

Another interesting aspect of the raised bogs of the Fraser Delta is

that these bogs seem to form the main organic phase of the delta evolutionary sequence. The backwaters and interdistributary areas of many other major river deltas, e.g. Mississippi, Orinoco, are the sites for major accumulation of organic deposits because the constantly wet conditions satisfy the requirements for a peat-forming template (Moore and Bellamy, 1973). It is interesting that in the Fraser Delta, extensive tree-dominated swamplands do not occur, and that the natural organic reservoir seems to be raised bogs. A map of the peat resources of the Fraser Lowland prepared by Anrep (1928) shows the considerable extent of bog deposits on the delta surface. Either there are not tree species in this part of North America that can be involved in organic accumulation in delta swamps, or the conditions are more favourable for the formation of raised bogs, so that potential swamp vegetation has no opportunity to become permanently established. Possibly with suitable vertical growth of these raised bogs, the crowns might become dry enough to support the growth of forest trees such as Tsuga (Rigg, 1925). Currently it seems that the bogs are still in the "youthful" active growth stage.

An interesting parallel in the formation of raised, deltaic, organic deposits can be found in the compound delta of the Klang and Langat Rivers of Malaysia (Coleman et al., 1970). Large mounds of organic material composed of logs and limbs are accumulating in the interdistributary areas, to levels above the impounding levees. Quite coincidentally, the peat accumulation in one of these "raised" organic deposits began at $4,540 \pm 100$ BP, very close to the time of initial organic accumulation in Burns Bog. The poor drainage in these Malaysian organic heaps, together with high rainfall and decreased evaporation (Coleman et al., 1970) appear to account

for organic accumulation above the water level; this is a situation similar to that in the Fraser Delta. It would be valuable to investigate other deltaic areas to determine what conditions are prerequisite for the development of such "raised" organic deposits.

The Relationship of the Main Paleoecologic Events in Burns Bog to the Development of the Fraser Delta

The results obtained from this study of Burns Bog provide an insight into the history of the southern section of the Fraser Delta.

Sea Level Changes: The upper part of the intertidal delta-front phase at the base of the three cores in this study corresponds essentially to sea level (Fig. 49). It also appears that at the time of the appearance of these sites above water, just after 5,000 BP, sea level must have been very near what it is today, with any difference probably being less than a meter.

In Boundary Bay, salt marsh peats, approximately at sea level (geodetic datum) are dated at 4,350 years BP (Kellerhals and Murray, 1969). These peats apparently directly overlie silts belonging to the intertidal delta-front phase (Hebda, unpublished results). This indicates that the emergence of the delta surface at the Boundary Bay locality occurred at the same time as at the three core sites in Burns Bog. This nearly synchronous emergence of four widely separated localities may indicate a local relative decline in sea level.

Recent studies of eustatic sea level changes in the southwestern Pacific Ocean (Bloom, 1970; Curray et al., 1970) and the western Atlantic Ocean (Redfield, 1967) seem to indicate that between 4,000 and 5,000 years ago sea levels were probably still rising, but that the rate of rise had

decreased considerably over previous rates. In addition, these workers concluded that sea levels in these areas in the Holocene never surpassed the current position although they may have approached it. Studies from Scandinavia seem to indicate a similar though gradually decreasing rate of sea level rise (with oscillations), with the current position being approached over the last 4,000 years (Mörner, 1971).

Clearly the local emergence of the southern Fraser Delta does not conform to the above pattern. The Fraser River Delta is being formed in a tectonically active area with uplift currently occurring in surrounding uplands (Mathews et al., 1970). Such tectonic activity, together with other movements such as earthquakes (Blunden, 1975) could easily account for the apparent sea level drop. Another possible explanation for the seemingly synchronous emergence relates to the rate of eustatic sea level change. If, as demonstrated for the western Pacific and Atlantic, the rate of sea level rise decreased between 4,000-5,000 years BP, then the rate of delta emergence (progradation) would be expected to increase, assuming the same rate of sediment input. Only small changes in the relationship of land to sea level are required for large expanses of deltaic flatlands to become emergent.

Following this local emergence, there is a marine transgression, recorded by salt marsh peats in core BBDC and Boundary Bay, but significantly not in cores CBB and DNR. Normally, such a transgression would imply a relative rise in sea level in the western and southern parts of the study area. Although this may be true, there is at least one alternative explanation that should be considered.

Currently in Boundary Bay, salt marsh peats form at about the mean high tide level which is 0-1 m above mean sea level (geodetic datum). Thus the salt marsh peat horizons (BBDC, Boundary Bay) formed at an elevation equivalent to or above the elevation of formation (0-1 m) of the upper intertidal delta-front silty peats which underlie them. This means that no change in sea level would have been necessary to account for the environmental change from estuarine marsh to salt marsh (e.g. BBDC - II to BBDC - III). A switch from fresh-brackish water influence (estuary) to salt water influence (tidal flats) would be all that was necessary for the vegetation and sedimentary change.

At least two explanations for this conversion are possible. The main channel of the Fraser River may have moved northward, thereby sharply decreasing fresh water and sediment supply to this part of the delta. Alternatively, the delta may have built out far enough to have joined Point Roberts to the mainland, thus preventing fresh-brackish estuarine water from flowing south along the edge of the delta to site BBDC. This is exactly what happens today, and is the main reason that Boundary Bay water is very saline. Zone BBDC - II represents a situation approximating the first permanently emergent horizon of the delta-front. The actual edge of the delta-front (-10 m level) would be expected to be located about 6 km further out to sea (Luternauer and Murray, 1973). At 4,400-4,100 BP this would mean that the submerged delta-front would have reached at least the lower slopes of the Point Roberts upland, joining it to the delta, likely indicating annexation of Point Roberts at this time.

Cut-off of sediment supply accompanied by continuing sediment subsidence through natural compaction, may also have promoted a marine transgression. Of course eustatic sea level changes, tectonic movements

(Mathews et al., 1970) and earthquakes (Blunden, 1975) should not be ruled out as additional factors for the slight relative rise in sea level.

The abrupt termination of the salt marsh phase in core BBDC, followed by sedge peats, containing slight traces of silt, seems to imply either a local sea level drop, or renewed flooding from the Fraser River, perhaps resulting from channel relocation. Following the termination of the salt marsh phase, there is no evidence of marine readvance in any of the cores.

The relative sea level changes suggested in the foregoing discussion seem to indicate some modifications to Blunden's sea level curve for the Fraser River Delta, at least for the southern part of the delta. First, as Blunden shows, relative sea level had reached its current position between 4,000 and 5,000 BP. Before this time, it may possibly have been above and not below present levels, as indicated by Blunden. Second, contrary to Blunden's curve, there seems to be no conclusive evidence that sea levels were significantly above those of the present between 2,000 and 4,000 BP.

With the current limited number of radiocarbon-dated sea level horizons for the 5,000-2,000 BP interval, it is not possible to arrive at any firm conclusions regarding exact sea level positions, or the causes and effects of local sea level change. More dates need to be obtained on horizons whose exact original elevation of formation is known with respect to sea level.

River Channel Changes: The results from Burns Bog also have some bearing on interpreting the position of the Fraser River channels in the past 5,000 years. The continuity of the deposits across Burns Bog seem to indicate that the Fraser River has not passed through the area in the last 5,000 years. This is opposite to the view expressed by Kellerhals and Murray

(1969). Channels would be expected to leave some trace in subsurface topography or sediments that should be reflected by vegetational differences on the surface (cf. the filled-in channel that runs northwest through Lulu Island (Blunden, 1975)). Unless such evidence is found, no case can be made for southward flow of the Fraser River into Boundary Bay since 5,000 BP.

Blunden (1975) has suggested that the South Arm of the Fraser River is very recent in origin (post-2,500 BP). According to him, it formed when the Fraser River, which was previously flowing to the northwest, breached the Greater Lulu Island Bog-Burns Bog raised bog complex, taking the path of least resistance to the Strait of Georgia.

Results from the cores do not clearly show any indication of such an event. It is likely that the sites were too far away from the river to be affected and that levees would have confined the river water. If such a southerly diversion occurred, a regional increase in alder would be expected, as this pioneering tree colonized the newly established banks of the river. Significant increases in alder do occur at the 2.5 m level in both cores CBB and BBDC. Although suggestive, this is not firm proof that avulsion occurred at that particular time; confirmation will have to come from detailed drilling along the river-bog contact faces.

In view of the fact that raised bog development is a natural phase of delta maturation, it is also possible that Lulu Island Bog and Burns Bog developed independently. However, this possibility seems remote in the light of the similarities in depth of peat and stratigraphy, opposed position of the bogs, and abrupt margins of the peat bogs against the river channel.

Application of the Study

The results of the present investigation have a number of applications:

1. First, the sequence of development in Burns Bog provides a basic framework for further investigation of Fraser Lowland raised bogs. This sequence can also be used as an example to which the paleoecology of other raised bogs in western North America can be compared.
2. The characterization of wetland vegetation types using palynomorph "fingerprints" (including microfossils other than pollen and spores of vascular plants) from surface samples of modern analogs provides a valuable tool for interpreting the paleoecology of depositional sites containing terrestrial peats. If more of these kinds of data were to be collected from wetland environments, precise reconstructions of the local histories of such sites could be made.
3. During the history of the bog, Sphagnum seems to have recolonized quickly areas that were destroyed by fire, just as it recolonizes badly disturbed areas today. This implies that the parts of the bog abandoned after peat mining can be expected to return to viable raised bog conditions in a relatively short period of time (50 years). This means that Burns Bog still retains the ability to maintain itself, and should not be abandoned as being beyond recovery.
4. The great contrast in peat accumulation rate for peat deposits (6.67 cm/100 years) and the Sphagnum hummock growth rate (82 cm/100 years) indicates that under ideal conditions a much greater yield of Sphagnum may be obtained. The peat cutting sites in Burns Bog seem to be ideal for this high rate of Sphagnum growth. If the demand for raw, clean Sphagnum increased (e.g. for filtration and absorption of heavy metal contaminants in water) Sphagnum

culture in these sites would appear to be a distinct possibility.

5. The success of this study in recognizing and dating the intertidal delta-front phase (i.e. sea level) means that additional radiocarbon dating of this horizon in the Fraser Delta and other coastal sites should provide an accurate method for elucidating the history of delta growth and sea level changes. The advantage of this technique is that dates can be obtained for autochthonous horizons rather than on materials such as logs and shells which may be allochthonous, and possibly not the same age as the matrix containing them.

6. Archeologists will be able to use the paleoecologic sequence established to interpret the history of neighbouring sites such as St. Mungo Cannery (Calvert, 1970) and Glenrose Cannery in terms of the environmental factors affecting the cultures.

7. The computer program developed here provides a quick method for calculating relative and absolute pollen values. It also facilitates the use of different combinations of taxa to obtain a clearer picture of changes in certain parts of the vegetation.

8. Most significantly, the identification of successional sequences sets the stage for predicting natural vegetational changes in the wetlands of the Fraser Lowland, and possibly other wetland sites of the north Pacific Coast. In addition, it provides the opportunity to forecast environmental consequences that might be expected where man disturbs the vegetation, peat or drainage of raised bogs.

THESIS SUMMARY

The following main conclusions have been reached from the analyses performed in this investigation:

1. Burns Bog developed on Fraser River deltaic deposits which appeared above sea level just after 5,000 years BP. The basal silty sand sequence, containing high percentages of Pinus and Picea pollen as well as recycled Tertiary pollen, indicates that river transport was very important in the formation of the palynomorph assemblages of these basal sediments. Local stands of Scirpus and Carex colonized the newly available land surface and contributed to the high Cyperaceae pollen levels.
2. After the initial colonization phase, the development of the bog progressed through three major stages; sedges, shrubs and Sphagnum. First sedges (perhaps with some grasses) occupied most of the area producing sedge peats. Eventually, shrubs such as Myrica and Spiraea appeared, either accompanied or closely followed by Ledum groenlandicum. In the central part of the bog, these shrubs were subsequently replaced (at $2,925 \pm 125$ BP) by Sphagnum bog conditions typical of the present raised bog.
3. At the western end of the bog, there was a short salt marsh phase ($4,125 \pm 100$ BP), characterized by chenopod and grass pollen. This was caused possibly by a shut-off of fresh/brackish water from the Fraser River, resulting from juncture of the delta to Point Roberts.
4. In the eastern section of the bog, at the foot of Panorama Ridge, the sedge-grass phase was only transient. It was closely followed by a

Myrica-Spiraea-Lysichitum swamp which lasted until the onset of true Sphagnum bog conditions in very recent times.

5. Fires have played an important role in the ecology of this Sphagnum bog. Periodically the vegetation of relatively high, dry sites was burned off, while wet depressions remained untouched. The unburned depressions maintained live Sphagnum and became centers of peat accumulation that eventually grew to an elevation above the surrounding burned areas. As a result, many of the burned sites were converted to depressions.
6. The AP spectrum of the three cores examined, indicates that the regional upland vegetation around the southern Fraser Delta remained essentially unchanged throughout the history of Burns Bog. On the delta proper, however, fluctuations in alder pollen were probably associated with colonization of levees along shifting river channels.
7. Recent logging and clearing of upland and delta sites have resulted in decreases in Abies, Tsuga, Pseudotsuga and Picea pollen levels while Alnus and grass pollen frequencies have increased markedly.
8. Three groups of ericad taxa, differentiated on the basis of tetrad diameter and pollen productivity, were found to reflect dry, intermediate and wet Sphagnum bog habitats. In this way a more precise interpretation of events in the Sphagnum phase was possible.
9. The relationships of pollen to the vegetation of selected wetland environments was studied by the use of surface samples. The results obtained were applied directly to the interpretation of vegetation and peat development in the cores. Although surface sample palynomorph spectra do not give a direct quantitative measure of the vegetation,

they do provide "fingerprints" by which vegetation types can be recognized in the sedimentary record of the bog.

10. The major paleoecologic changes indicated by peat and pollen stratigraphy, result mainly from successional processes that are still observable in the Fraser Lowland, rather than from climatic changes. This suggests that more emphasis should be placed on understanding normal ecologic processes in wetlands (particularly bogs). Although climatic changes can play an important part in vegetation change, they may be subordinate to the effects of sedimentary processes, physiographic changes and successional trends.

As far as the author knows this is the first detailed outline of raised bog development in western North America. This study demonstrates that studies of current vegetation and pollen-vegetation relationships can be combined with palynologic investigations to reconstruct the history of a raised bog. Hopefully, the increased understanding gained from this study of raised bog deposits will lead to both an increased recognition of the rather special circumstances in the development of raised bogs, and to controlled utilization as well as preservation of the raised bogs of the Fraser Lowland and Pacific Coast.

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APPENDIX 1: SPECIES COMPOSITION OF THE VEGETATION TYPES OF
BURNS BOG, DELTA, BRITISH COLUMBIA

This appendix contains the data from which the vegetation type descriptions were made (Ch. 2) and from which the vegetation map (Fig. 4) was produced. The species cover data are presented according to the following cover estimate scale modified from the Braun-Blanquet scale (Mueller-Dombois and Ellenberg, 1974):

<u>Percentage Range</u>	<u>Verbal Equivalent</u>	<u>Symbol</u>
50-100	Dominant	<i>DOM</i>
25-50	Very common	<i>VCM</i>
5-25	Common	<i>COM</i>
1-5	Occasional	<i>OCC</i>
Less than 1		<i>#</i>
Absent		-

The bracketed numbers in italics that follow cover designations in the table are the actual average percentage cover values for vegetation types where five or more quadrats were investigated (averaging less than 5 quadrats was considered not to give a meaningful value). Non-italicized numbers in brackets are species frequencies (number of quadrats containing species/total number of quadrats of the vegetation type). Frequency (together with average cover where possible) is used for herbs, ferns, mosses, liverworts and lichens which were estimated in 1 m x 1 m quadrats. Frequency is a better measure of the role of these plants which are ubiquitous in the

vegetation but have low cover. Solitary + signs denote that a species is present within the vegetation type but was not encountered in quadrats studied. Of the 60 quadrats examined, 6 were judged to be intermediate in nature between vegetation types. The cover values of these 6 quadrats were excluded from averages.

TABLE 5: AVERAGE SPECIES COVER FOR THE VEGETATION TYPES OF BURNS BOG, DELTA, B. C.

Species	Heathland	Pine Woodland	Birch Woodland	<i>Spiraea</i> Brushland	Mixed Coniferous Woodland	Salmonberry Bushland	Alder Woodland
Number of 10 m x 10 m quadrats	20	11	3	3	8	6	3
Number of 1 m x 1 m quadrats	100	55	15	15	40	30	15
<u>Gymnosperm Trees</u>							
<i>Picea sitchensis</i>	-	+	+	+	COM(14)	OCC(4)	OCC
<i>Pinus contorta</i>	VCM(38)	DOM(53)	+	OCC	OCC(5.5)	+	-
<i>Taxus brevifolia</i>	-	-	-	-	+	+	+
<i>Thuja plicata</i>	-	+	-	-	VCM(36)	COM(22)	OCC
<i>Tsuga heterophylla</i>	+	+	-	-	COM(15)	OCC(4)	+
<u>Angiosperm Trees</u>							
<i>Acer circinatum</i>	-	-	-	-	OCC(2.5)	-	OCC
<i>Acer macrophyllum</i>	-	-	-	-	+	-	-
<i>Alnus rubra</i>	-	-	-	-	OCC(2)	VCM(28)	DOM
<i>Betula occidentalis</i>	+	OCC(3.5)	DOM	COM	COM(10)	COM(12)	OCC
<i>Crataegus douglasii</i>	-	-	+	-	-	+	-
<i>Ilex aquifolium</i>	-	-	+	-	+	-	-
<i>Populus tremuloides</i>	-	-	+	+	-	+	-
<i>Populus balsamifera</i> subsp. <i>trichocarpa</i>	-	-	-	+	-	+	-

Table 5 (Continued)

<u>Species</u>	<u>Heathland</u>	<u>Pine Woodland</u>	<u>Birch Woodland</u>	<u>Spiraea Brushland</u>	<u>Mixed Coniferous Woodland</u>	<u>Salmonberry Bushland</u>	<u>Alder Woodland</u>
<u>Angiosperm Trees (cont.)</u>							
<i>Malus fusca</i>	-	-	OCC	OCC	OCC(6.5)	COM(23)	COM
<i>Rhamnus purshianus</i>	-	-	COM	-	OCC(2.5)	COM(17)	COM
<i>Salix hookeriana</i>	-	-	OCC	+	-	+	-
<i>Salix lasiandra</i>	-	-	OCC	-	-	OCC(2)	OCC
<i>Sorbus aucuparia</i>	-	+	+	-	+	+	+
<u>Shrubs</u>							
<i>Amelanchier alnifolia</i>	-	-	-	-	-	+	-
<i>Andromeda polifolia</i>	COM(5)	+	-	-	-	-	-
<i>Cornus sericea</i> subsp. <i>occidentalis</i>	-	-	-	-	OCC(2.5)	COM(19)	-
<i>Empetrum nigrum</i>	+	-	-	-	-	-	-
<i>Gaultheria shallon</i>	COM(13)	VCM(45)	OCC	COM	DOM(51)	COM(9)	+
<i>Kalmia microphylla</i> subsp. <i>occidentalis</i>	COM(9)	OCC(1.5)	-	-	-	-	-
<i>Ledum groenlandicum</i>	DOM(69)	DOM(62)	COM	OCC	OCC(4)	-	-
<i>Lonicera involucrata</i>	-	-	+	-	-	VCM(25)	OCC
<i>Menziesia ferruginea</i>	-	-	-	-	COM(11)	OCC(3)	OCC
<i>Myrica gale</i>	-	-	COM	+	+	+	-
<i>Ribes lacustre</i>	-	-	-	-	-	+	+

Table 5 (Continued)

Species	Pine		Birch		<i>Spiraea</i>		Mixed		Alder	
	Heathland	Woodland	Woodland	Woodland	Brushland	Woodland	Coniferous	Salmonberry	Woodland	Woodland
<u>Shrubs (cont.)</u>										
<i>Rosa nutkana</i>	-	-	-	-	+	-	-	-	-	-
<i>Rosa pisocarpa</i>	-	-	-	-	-	-	-	+	-	-
<i>Rubus discolor</i>	-	-	-	-	-	-	-	+	-	-
<i>Rubus laciniatus</i>	-	-	-	-	-	OCC(4.5)	+	+	-	-
<i>Rubus parviflorus</i>	-	-	-	-	-	+	+	+	-	-
<i>Rubus spectabilis</i>	-	-	OCC	-	-	COM(8)	+	DOM(69)	VCM	+
<i>Rubus ursinus</i>	-	-	-	-	-	-	-	+	-	-
<i>Sambucus racemosa</i>	-	-	+	+	-	+	+	OCC(1.5)	OCC	+
<i>Spiraea douglasii</i>	+	COM(5.4)	DOM	DOM	DOM	COM(10)	+	COM(9)	+	+
<i>Vaccinium alaskaense</i>	-	-	-	-	-	+	+	+	-	-
<i>Vaccinium deliciosum</i>	+	+	-	-	-	-	-	-	-	-
<i>Vaccinium myrtilloides</i>	COM(15)	COM(19)	OCC	OCC	+	+	+	-	-	-
<i>Vaccinium ovalifolium</i>	-	+	-	-	-	COM(7.5)	+	OCC(3)	+	+
<i>Vaccinium parvifolium</i>	-	-	-	-	-	OCC(2)	+	COM(8)	OCC	+
<i>Vaccinium uliginosum</i>	VCM(39)	COM(6)	-	-	-	-	-	-	-	-
<i>Viburnum edule</i>	-	-	-	-	-	+	+	+	OCC	+

Table 5 (Continued)

Species	Heathland	Pine Woodland	Birch Woodland	<i>Spiraea</i> Brushland	Mixed Coniferous Woodland	Salmonberry Bushland	Alder Woodland
<u>Herbs</u>							
<i>Cardamine breweri</i>	-	-	-	+	-	+(3)	-
<i>Carex lenticularis</i>	-	+(3.5)	-	-	+(8.5)	-	-
<i>Carex obnupta</i>	-	+	-	-	-	-	-
<i>Carex pauciflora</i>	+	-	-	-	-	-	-
<i>Carex paupercula</i>	+	+	-	-	-	-	-
<i>Carex phyllomanica</i>	+	-	-	-	-	-	-
<i>Carex rostrata</i>	-	-	+	-	-	-	-
<i>Circaea alpina</i>	-	-	-	-	-	-	+
<i>Claytonia sibirica</i>	-	-	-	-	-	-	OCC (27)
<i>Cornus unalaschkensis</i>	-	-	+	-	-	-	-
<i>Drosera anglica</i>	+(3)	-	-	-	-	-	-
<i>Drosera rotundifolia</i>	OCC (1,17)	+	-	-	-	-	-
<i>Dulichium arundinaceum</i>	+	-	-	-	-	-	-
<i>Epilobium angustifolium</i>	-	-	+(7)	+	+(13)	+	-
<i>Epilobium minutum</i>	-	-	+	+	-	-	-
<i>Eriophorum chamissonis</i>	+(31)	+	-	-	-	-	-
<i>Galeopsis tetrahit</i>	-	-	+	-	-	-	-
<i>Galium aparine</i>	-	-	-	-	+(33)	-	-

Table 5 (Continued)

Species	Heathland	Pine Woodland	Birch Woodland	<i>Spiraea</i> Brushland	Mixed Coniferous Woodland	Salmonberry Bushland	Alder Woodland
<u>Herbs (cont.)</u>							
<i>Galium ?triflorum</i>	-	-	-	-	+	+(3)	-
<i>Glyceria grandis</i>	-	-	+	-	-	+(7)	-
<i>Holcus lanatus</i>	-	-	+	+(7)	+(12)	-	-
<i>Juncus effusus</i>	-	-	-	-	-	+	-
<i>Lycopus uniflorus</i>	-	-	-	+	-	-	-
<i>Lysichitum americanum</i>	-	-	-	-	COM(14,20)	COM(13,20)	VCM(60)
<i>Lysimachia thursiflora</i>	-	-	-	+	-	-	-
<i>Maianthemum dilatatum</i>	-	-	-	-	OCC(1,12.5)	OCC(2,5.5)	-
<i>Myosotis laxa</i>	-	-	-	-	-	+	-
<i>Nuphar lutea</i> subsp. <i>polysepala</i>	+(1)	-	-	-	-	-	-
<i>Oenanthe sarmentosa</i>	-	-	+	-	+	OCC(4.5, 20)	-
<i>Phalaris arundinacea</i>	-	-	-	+	-	-	-
<i>Phleum pratense</i>	-	-	-	-	+(5)	-	-
<i>Rhynchospora alba</i>	OCC(2.5, 28)	+	-	-	-	-	-
<i>Rubus chamaemorus</i>	+(38)	+(5.5)	-	-	-	-	-

Table 5 (Continued)

Species	Heathland	Pine Woodland	Birch Woodland	<i>Spiraea</i> Brushland	Mixed Coniferous Woodland	Salmonberry Bushland	Alder Woodland
<u>Herbs (cont.)</u>							
<i>Rumex acetosella</i>	-	-	-	-	+	-	+
<i>Scutellaria lateriflora</i>	-	-	+	-	+	OCC (1)	-
<i>Solanum dulcamara</i>	-	-	-	-	-	+	-
<i>Stachys cooleyae</i>	-	-	-	-	-	-	+
<i>Stellaria crispa</i>	-	-	+	-	+	+(10)	+(7)
<i>Tiarella trifoliata</i>	-	-	-	-	-	+	-
<i>Tofieldia glutinosa</i>	+	-	-	-	-	-	-
<i>Trientalis europaea</i> subsp. <i>arctica</i>	-	-	+	+(27)	-	-	-
<i>Trifolium repens</i>	-	-	-	-	+	-	-
<i>Typha latifolia</i>	+	-	-	-	-	-	-
<i>Vaccinium oxycoccos</i>	COM(7,65)	+(14.5)	-	-	-	-	-
<i>Viola palustris</i>	-	-	-	-	+	+	-
<u>Ferns</u>							
<i>Athyrium filix-femina</i>	-	-	-	-	COM(6,25)	COM(6,53)	OCC(3,53)
<i>Dryopteris assimilis</i>	-	-	+	-	COM(7,15)	OCC(1,20)	OCC(1,20)
<i>Polypodium glycyrrhiza</i>	-	-	-	-	+	+(17)	+

Table 5 (Continued)

Species	Heathland	Pine Woodland	Birch Woodland	<i>Spiraea</i> Brushland	Mixed Coniferous Woodland	Salmonberry Bushland	Alder Woodland
<u>Ferns (cont.)</u>							
<i>Polystichum munitum</i>	-	-	-	-	+(5)	OCC (2,23)	OCC (3,60)
<i>Pteridium aquilinum</i>	OCC (2,19)	COM (18, 60)	COM (8,33)	COM (19, 57)	OCC (2,15)	-	-
<u>Mosses</u>							
<i>Antitrichia curti- pendula</i>	-	-	-	-	+	+(7)	+(7)
<i>Aulacomnium androgynum</i>	+(4)	+(9)	+(33)	+	+	+(10)	-
<i>Aulacomnium palustre</i>	+	+	-	+(7)	-	+	-
<i>Brachythecium</i> sp.	-	+	-	-	-	+	+(7)
<i>Cladopodium crispi- folium</i>	-	-	-	-	+	+(3)	+(7)
<i>Dicranum fuscescens</i>	-(1)	+(4)	-	+	+	+	+
<i>Dicranum scoparium</i>	+(7)	OCC (4,35)	+	+(7)	+(3)	-	+
<i>Drepanocladus uncinatus</i>	-	-	+	-	-	+	-
<i>Fontinalis</i> sp.	-	-	-	-	-	+	-
<i>Homalothecium fulge- scens</i>	-	-	+	-	-	-	+(7)
<i>Hylocomium splendens</i>	+	+(7)	+(7)	+(7)	+(10)	OCC (1,30)	+(7)
<i>Hypnum circinale</i>	+	+	+(7)	+	+	+(13)	+(7)

Table 5 (Continued)

Species	Pine		Birch	Spiraea		Mixed		Salmonberry		Alder	
	Heathland	Woodland	Woodland	Brushland	Woodland	Coniferous	Woodland	Bushland	Woodland	Woodland	Woodland
<u>Mosses (cont.)</u>											
<i>Isopterygium elegans</i>	-	-	+	-	+	+	+	-	-	+	(7)
<i>Isotheicum spiculiferum</i>	+	+(5)	+(20)	+	+	+(18)	+	COM(5,77)	COM(6,60)		
<i>Leucolepis menziesii</i>	-	-	-	-	-	+(5)	+	+	+	+	
<i>Metaneckera menziesii</i>	-	-	-	-	-	+(3)	+	+	+	+	
<i>Mnium glabrescens</i>	-	+	+	-	-	+(23)	+	COM(5,80)	+	+(47)	
<i>Mnium spinulosum</i>	-	-	-	-	-	+	+	+(10)	OCC(1,40)		
<i>Orthotrichum consimile</i>	-	-	+	-	-	+(5)	+	+(33)	+	+(27)	
<i>Orthotrichum byelli</i>	-	-	-	-	-	-	-	+	+	+(7)	
<i>Plagiotheicum undulatum</i>	-	+(2)	+	-	-	+(23)	+	OCC(2,55)	+	+(7)	
<i>Pleurozium schreberi</i>	+	+(5)	+	+	+	+	+	-	+	+	
<i>Polytrichum commune</i>	-	+	+	+(7)	+	+	+	+	+	+	
<i>Polytrichum juniperinum</i>	OCC(2,38)	OCC(1,22)	+	COM(6,53)	+	+	+	+	-	-	
<i>Ptilium cristacastrensis</i>	-	-	-	-	+	+	+	+	-	-	
<i>Rhytidiadelphus loreus</i>	+(5)	+(9)	+	+	+(3)	+	+	+	+	+(33)	
<i>Rhytidiadelphus triquetrus</i>	+(2)	OCC(2,7)	+	+(13)	+(8)	+	+	+	+	+(20)	

Table 5 (Continued)

Species	Heathland	Pine Woodland	Birch Woodland	<i>Spiraea</i> Brushland	Mixed Coniferous Woodland	Salmonberry Bushland	Alder Woodland
<u>Mosses (cont.)</u>							
<i>Sphagnum capillaceum</i> var. <i>tenellum</i>	COM(12, 59)	COM(8,36) +	-	-	+	-	-
<i>Sphagnum fuscum</i>	OCC(1,8)	OCC(4)	-	-	-	-	-
<i>Sphagnum papillosum</i>	OCC(1,10)	+	-	-	-	-	-
<i>Sphagnum recurvum</i>	COM(1,27)	+(13)	+(13)	-	+	-	-
<i>Sphagnum squarrosum</i>	-	+	-	-	+(3)	-	+
<i>Sphagnum tenellum</i>	OCC(2,18)	+	-	-	-	-	-
<i>Stokesiella oregana</i>	OCC(2,27)	COM(11, 80)	OCC(4, 93)	OCC(3,60)	COM(6,52)	COM(9,87)	COM(6,80)
<i>Stokesiella praelonga</i>	-	-	-	-	+(10)	OCC(1,63)	+(20)
<i>Tetraphis pellucida</i>	-	+(2)	-	-	+	-	+
<u>Liverworts</u>							
<i>Frullania tamarisci</i> subsp. <i>nisquallensis</i> (Sull.) Hatt.	-	-	-	-	+(3)	+(10)	+
<i>Gymnocola inflata</i> (Huds.) Dum.	+(3)	-	-	-	-	-	-

Table 5 (Continued)

Species	Heathland	Pine Woodland	Birch Woodland	<i>Spiraea</i> Brushland	Mixed Coniferous Woodland	Salmonberry Bushland	Alder Woodland
<u>Liverworts (cont.)</u>							
<i>Mylia anomala</i> (Hook.) S. Gray	+(8)	-	-	-	-	-	-
<i>Pellia</i> cf. <i>neesiana</i> (Gott.) Limpr.	-	-	-	-	OCC(2,10)	OCC(1,10)	-
<i>Porella</i> sp.	-	-	-	-	+	+(10)	+(27)
<i>Radula</i> sp.	-	-	-	-	-	-	+(13)
<i>Scapania bolanderi</i> Aust.	-	-	-	-	+	+(7)	+(7)
<u>Lichens</u>							
<i>Cladina</i> spp.	COM(10, 55)	OCC(2,11)	-	-	-	-	-
<i>Cladonia</i> spp.	COM(5,62)	+(13)	+(20)	-	-	-	-
<i>Hypogymnia</i> spp.	+(83)	+(42)	+(7)	-	-	-	-
<i>Platismatia</i> sp.	-	+(13)	-	-	-	-	-
<i>Usnea</i> sp.	+(8)	+(11)	+(13)	-	-	-	-

APPENDIX 2: COMPUTER PROGRAMS USED TO CALCULATE RELATIVE AND ABSOLUTE
POLLEN VALUES FOR COMPUTER PLOTTED POLLEN DIAGRAMS

These programs calculate percentages or absolute values for all species at one depth. The results are stored in POLLEN and eventually output, one species at a time (not one depth at a time) into the file that will be used by the plotting program. The values are output in a format that can be used by the general plotting program SPLOT (Lauriente, unpublished) to create a standard pollen diagram. A specific example with real values is used in the following sections for illustrating the programs.

Appendix 2a: Program for calculating relative pollen frequencies.

Preliminary cards

```
$JOB HEBDA[101,4] /TIME: 45; POLLEN DIAGRAM
$RUN FORTRN
*MAIN,LP: <BI:/OH/OP:O/CK
```

Main program

```
1      DIMENSION DEPTH(90),POLSTR(35),TOTALP(90),EXCLD1(90)
      C DEPTH, TOTALP, EXCLD1 must equal the number of samples + 2
      C POLSTR( ) must be greater than the number of species to be
      C included in the percentage calculations.
2      DIMENSION POLLEN(90,68)
      C POLLEN( , ) is the array in which values are stored for
      C eventual output. The second number (e.g. 68) must be
      C twice as large as the number of species because room must
      C be available for 10 x expanded values.
3      IN=5
4      IO=6
5      IND=0
6      J=0
7      L=1
8      M=1
9      SMPLES=84.
      C number of samples + 2
10     SP=3000.
      C number of species x 100
11     1 READ(IN,100,END=2)DPHIN
      C Reads in all depths (1 per data card) corresponding to
      C samples in core.
12     100 FORMAT(1F5.0)
```

```

13      DEPTH(L)=-DEPTHIN*.01
14      L=L+1
15      IF(L.GT. SMPLES)GO TO 2
16      GO TO 1
17  2    J=J+1
18      IF(J. GT. SMPLES)GO TO 60
19      TOTAL=.1
20      I=1
21  3    READ(IN,101,END=90)POLCNT
      C    Reads in pollen counts (1 per data card) for all species
          at one depth.
22  101  FORMAT(1F5.0)
23      POLSTR(I)=POLCNT
24      TOTAL=TOTAL+POLSTR(I)
      C    Totals all pollen counts for a sample
25      I=I+1
26      IF(I.GT.SP/100)GO TO 10
27      GO TO 3
28  10   S=0.0
29      TOTALP(J)=(TOTAL/10.)+SP
      C    Outputs total for each sample so that the number of grains
          comprising the sum can be graphed on the diagram.
30      READ(IN, 101)FRNCNT
      C    Reads in count for pollen and spore types to be excluded
          from the total (e.g. ferns in this case).
31      EXCLD1(J)=SP+100.+(FRNCNT*100./TOTAL)
      C    Calculates excluded counts as a percent of the total.
32      IF(EXCLD1(J).GT.3400.)EXCLD1(J)=3400.
33      JK=1
34      K=1
35  11   PCNT=(POLSTR(JK)*100/TOTAL)+S
      C    Calculates the percent of each species.
36      POLLEN(J,K)=PCNT
37      K=K+1
38      PCNTEX=(PCNT-S)*10+S
      C    Calculates the 10x expansion of the percentage.
39      IF(PCNTEX.LT.100.+S)GO TO 50
40      PCNTEX=S+100
41  50   POLLEN(J,K)=PCNTEX
42      K=K+1
43      S=S+100.
      C    Adding 100 to S serves to shift the values for the next
          species along the x axis in the pollen diagram.
44      IF(S.GT.SP)GO TO 2
45      JK=JK+1
46      GO TO 11
      C    START OF WRITING SEQUENCE - writes in output values arranged
          in correct order and format for use by the plotting program.
47  60   N=1
48  61   WRITE(10,102)POLLEN(N,M),DEPTH(N),IND

```



```

49 102  FORMAT(2F10.3,13)
50      N=N+1
51      IF(N.GT.SMPLES)GO TO 62
52      GO TO 61
53 62    M=M+1
54      IF(M.GT.2*SP/100)GO TO 90
55      GO TO 60
56 90    KK=1
57 94    WRITE (10,102)TOTALP(KK),DEPTH(KK),IND
58      KK=KK+1
59      IF(KK.GT.SMPLES)GO TO 91
60      GO TO 94
61 91    KK=1
62 97    WRITE(10,102)EXCLD1(KK),DEPTH(KK),IND
63      KK=KK+1
64      IF(KK.LE.SMPLES)GO TO 97
65 96    IND=1
66      STOP
67      END
      C      End of main program
$RUN LINK
#MAIN,LP:/SH<MAIN/CC/B:50000,FTNLIB/E
$KILL
$UNIX RM MAIN. OBJ
$UNIX LN /TMP/DATA TMP
$ASSIGN SY:TMP,5
$ASSIGN SY:POLLEN,6
$RUN MAIN

```

Data cards are included after the \$RUN MAIN card.
Data cards should be arranged as follows:

Set of n cards, one for each depth, containing depth value with the first and last depth repeated twice (necessary to obtain standard looking pollen diagram).
n sets containing m cards, where m is the number of species, with one pollen count per card. Species arrangement in the data deck (containing m cards) should be the same as it would read from left to right on the pollen diagram.

```

$ASSIGN
$ASSIGN SY:POLLEN,1
$RUN SPLOT

```

SPLOT cards would follow.

Appendix 2b: Program for calculating absolute pollen concentrations
per cubic centimeter.

Only the major differences from Appendix 2a are explained.

Preliminary cards same as in Appendix 2a.

Main program

```

1      DIMENSION DEPTH(42),EXOTIX(42),VOLSED(42),WGTS(42),
      VOLSAM(42)
2      DIMENSION VOLSSM(42),POLSTR(64),ABTOTV(42),ABSLTV(42,65)
      C      Differs from Appendix 2a by the inclusion of values
      necessary for calculating and outputting absolute values.
3      IN=5
4      IO=6
5      IND=0
6      CONSTX=762000.
      C      CONC. OF EXOTIC SOLUTION USED * VOL. OF SOLUTION ADDED
7      M=1
8      L=1
9      J=0
10     SMPLES=40.
11     SP=3100.
      C      NUMBER OF SPECIES BEING CALCULATED * 100.
12     1      READ(IN,100,END=2)DPHTIN,EXTXIN,VSEDIN,WS(42),VSAMIN,VSSMIN
      C      Along with depth, this command reads in other values
      necessary for calculating absolute pollen concentrations.
13     100    FORMAT(6F7.2)
14            DEPTH(L)=DPHTIN*.01
15            EXOTIX(L)=EXTXIN
16            VOLSED(L)=VSEDIN
17            WGTS(L)=WS(42)
18            VOLSAM(L)=VSAMIN
19            VOLSSM(L)=VSSMIN
20            L=L+1
21            IF(L.LE.SMPLES)GO TO 1
22     2      J=J+1
23            IF(J.GT.SMPLES)GO TO 60
24            RV=VOLSSM(J)/VOLSAM(J)
25            TOTAL=.1
26            I=1
27     3      READ(IN,101,END=90)POLCNT
28     101    FORMAT(1F5.0)
29            POLSTR(I)=POLCNT
30            TOTAL=TOTAL+POLSTR(I)
31            I=I+1
32            IF(I.GT.SP/100)GO TO 10

```

```

33      GO TO 3
34  10    S=0.0
35      ABTOT=(TOTAL*CONSTX/(EXOTIX(J)*1000.*RV*VOLSED(J)))
      C    Calculates absolute concentration of total pollen
           and spores.
36      ABTOTV(J)=ABTOT/10.+SP
37      K=1
38      JK=1
39  11    RP=POLSTR(JK)/EXOTIX(J)
40      ABSLT=(RP*CONSTX/(1.0000.*RV*VOLSED(J)))+S
      C    Calculates absolute concentration of each pollen
           and spore type.
41      ABSLTV(J,K)=ABSLT
42      K=K+1
43      ABSLTX=(ABSLT-S)*10.+S
44      IF (ABSLTX.LT.100.+S) GO TO 50
45      ABSLTX=S+100.
46  50    ABSLTV(J,K)=ABSLTX
47      K=K+1
48      JK=JK+1
49      S=S+100.
50      IF (S.GT.SP) GO TO 2
51      GO TO 11
      C    START OF WRITING SEQUENCE
52  60    N=1
53  61    WRITE (10,102) ABSLTV(N,M),DEPTH(N),IND
54  102   FORMAT(2F10.3,I3)
55      N=N+1
56      IF (N.LE.SMPLES) GO TO 61
57  62    M=M+1
58      IF (M.GT.2*SP/100) GO TO 90
59      GO TO 60
60  90    KK=1
61  94    WRITE (10,102) ABTOTV(KK),DEPTH(KK),IND
62      KK=KK+1
63      IF (KK.LE.SMPLES) GO TO 94
64      IND=1
65      STOP
66      END

```

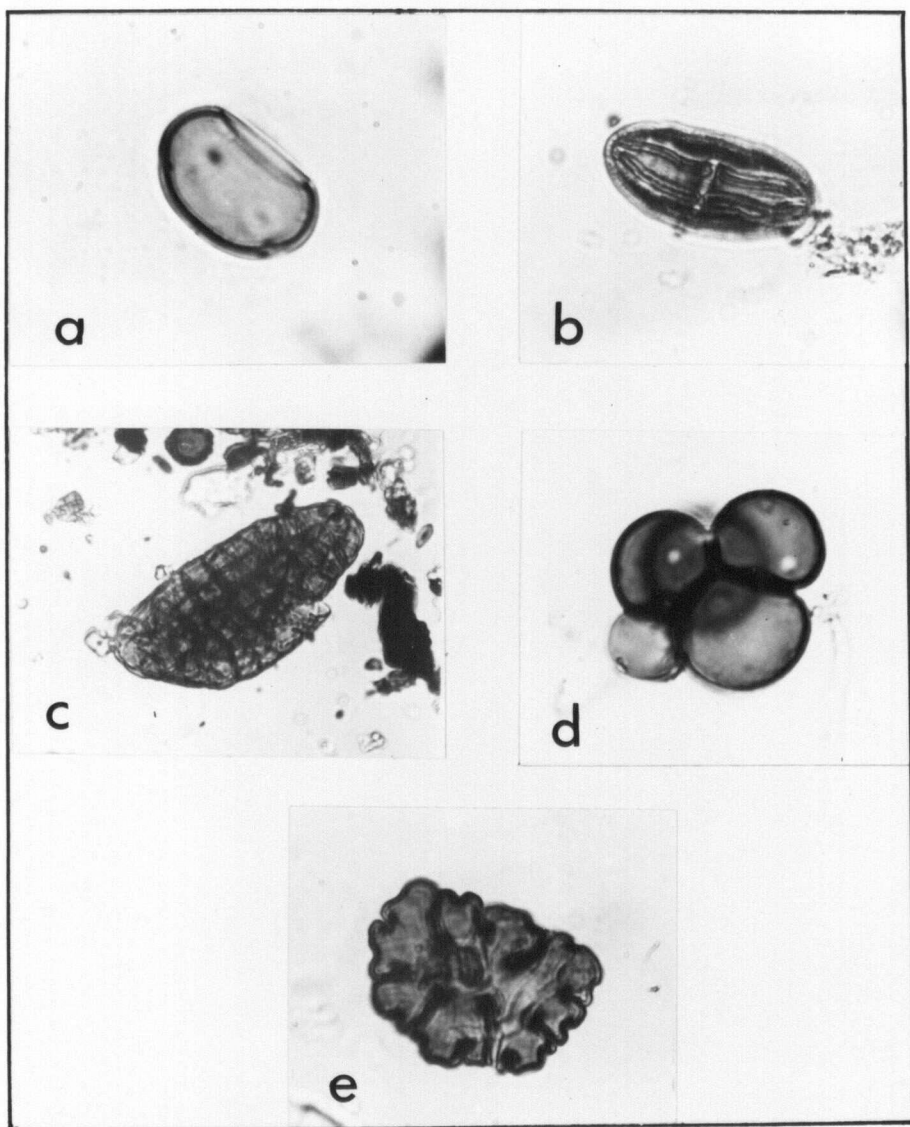
End of main program.

For rest of program, see Appendix 2a.

Data cards are arranged as in Appendix 2a, except that the n cards containing depths also contain the pertinent values necessary for determining absolute pollen concentrations.

Figure 51: Selected palynomorphs recovered from Burns Bog sediments.

- a) Type 1 (1,000X)
- b) Oenanthe sarmentosa (1,000X)
- c) Van Geel type 3 (V.G. 3) (400X)
- d) cf. Periconia (1,000X)
- e) Desmidiospora (1,000X)



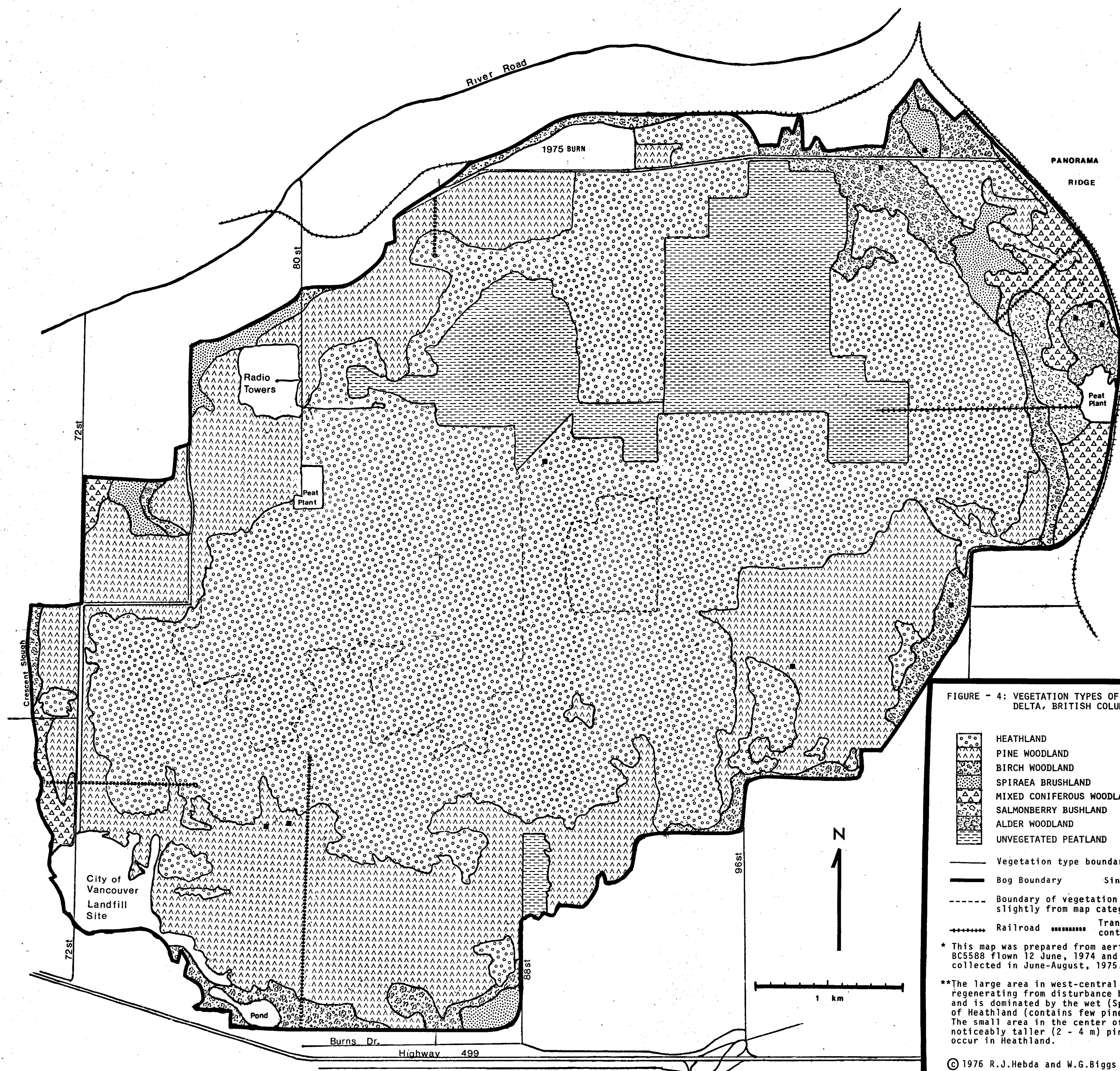


FIGURE - 4: VEGETATION TYPES OF BURNS BOG, DELTA, BRITISH COLUMBIA.*

- HEATHLAND
- PINE WOODLAND
- BIRCH WOODLAND
- SPIRAEA BRUSHLAND
- MIXED CONIFEROUS WOODLAND
- SALMONBERRY BRUSHLAND
- ALDER WOODLAND
- UNVEGETATED PEATLAND
- Vegetation type boundary, roads
- Bog Boundary
- Single quadrats
- Boundary of vegetation differing slightly from map category**
- Railroad
- Transect line containing quadrats

* This map was prepared from aerial photography BC5588 flown 12 June, 1974 and field data collected in June-August, 1975.

**The large area in west-central Burns Bog is regenerating from disturbance by peat mining and is dominated by the wet (Sphagnum) subtype of Heathland (contains few pines). The small area in the center of the bog contains noticeably taller (2 - 4 m) pines than usually occur in Heathland.

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