DEVELOPMENT OF A SALT MARSH ON THE FRASER DELTA AT BOUNDARY BAY, BRITISH COLUMBIA, CANADA

by

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Salt marshes are "areas of land bordering on the sea, more or less covered with vegetation and subject to periodic inundation by the tide. They originate as bare mud- or sand-flats which, as they become higher, are colonized by algae and flowering plants, the species involved varying in different parts of the world. The plants are enabled to occupy this habitat by virtue of their tolerance of the special conditions obtaining in marshes. The advent of the plants on the bare flats promotes further growth in height of the land which, as this 'rising' takes place, results in changes in the environment so that different species can enter the area. Salt marshes, therefore, may extend vertically from about mean sea level up to the extreme upper limit of the tides, where they will abut on normal land vegetation or else grade into freshwater swamp."

(Chapman, 1960, p. 1)

ABSTRACT

The development of a late Holocene salt marsh was studied on the inactive part of the Fraser Delta at Boundary Bay, southwestern British Columbia. Present-day vegetation zones near 64th Street, South Delta, in the western part of the Bay, were distinguished in the salt marsh and were related to zones found in cores obtained in a transect across the marsh. A sequence of development, related to elevation, was determined. _Salicornia_ and _Triglochin_ are pioneer colonizers of the tidal flats and are sometimes associated with areas elevated by algal mats. As the area was elevated, sediments were trapped by vegetation and stabilized by rhizomes, and other halophytes grew, including _Cuscuta_, _Spergularia_, _Atriplex_, _Distichlis_, _Grindelia_, and _Plantago_. A zone characterized by abundant _Atriplex_ represents positions of former strandlines. As further emergence occurred, mesophytes became dominant and, in the landward, most emergent zone, a diverse flora of _Malus_, _Sidalcea_, _Aster_, _Achillea_, _Solidago_, _Elymus_, _Angelica_, _Juncus_, and grasses developed. A radiocarbon date on _Salicornia_-rich organic silts at a depth of 35 to 40 cm in core 5 suggests that salt marsh development commenced 320 ± 70 years B.P. (GSC-3186).

A former salt marsh peat is now partially buried and being actively eroded where exposed near 112th Street, South Delta, in eastern Boundary Bay. A paleoenvironmental reconstruction suggests the peat started developing in freshwater, with ferns, sedges, _Typha_, and _Nuphar_. Later, it was successively inundated by marine water and a salt marsh developed, as seen by an in-

crease in the abundance of chenopod pollen. Subsequent emergence of the salt marsh was accompanied by the development of an increasingly diverse vegetation.

TABLE OF CONTENTS.

TABLE OF CONTENTS (cont'd)

LIST OF TABLES.

LIST OF FIGURES.

LIST OF FIGURES (cont'd).

LIST OF FIGURES (cont'd).

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CHAPTER 1: INTRODUCTION

The subaqueous part of the lower delta plain of the Fraser Delta is a broad, gently sloping tidal flat which is 6 km wide on the active western portion of the delta and 4 km wide on the inactive, south-facing portion. Salt marshes are locally developed on the uppermost emergent parts of the tidal flats. The distribution of salt marsh has been mapped by Becker (1971), Forbes (1972), and Yamanaka (1975). Moody (1978) studied the marshes at Brunswick Point, and a summary report of the marsh communities was prepared by Envirocon (1980). The present study is concerned with the development of the salt marsh on a small area of the tidal flats in Boundary Bay, on the inactive southern-facing delta front (Figure 1). The marsh is the least influenced by the Fraser River of all the marshes developed on the tidal flats (Parsons, 1975; Yamanaka, 1975).

The study area is located 19 km south of Vancouver, British Columbia, at Lat. 49°04' N and Long. 123°00' W (Figure 1). It is separated from the active western delta front and protected from the Strait of Georgia by Point Roberts, thus having relatively small wave heights. Salt marsh development in Boundary Bay is not uniform; at 64th Street, South Delta, an extensive marsh was chosen for study (Figure 2). This marsh is broader and has better developed plant zonation than on other parts of the Fraser Delta. The sedimentary processes of the tidal flats seaward of the marshes were studied by Swinbanks (1979), and Kellerhals and Murray (1969) described the tidal flats. The salt marsh is the last major zone whose sedimentary history has

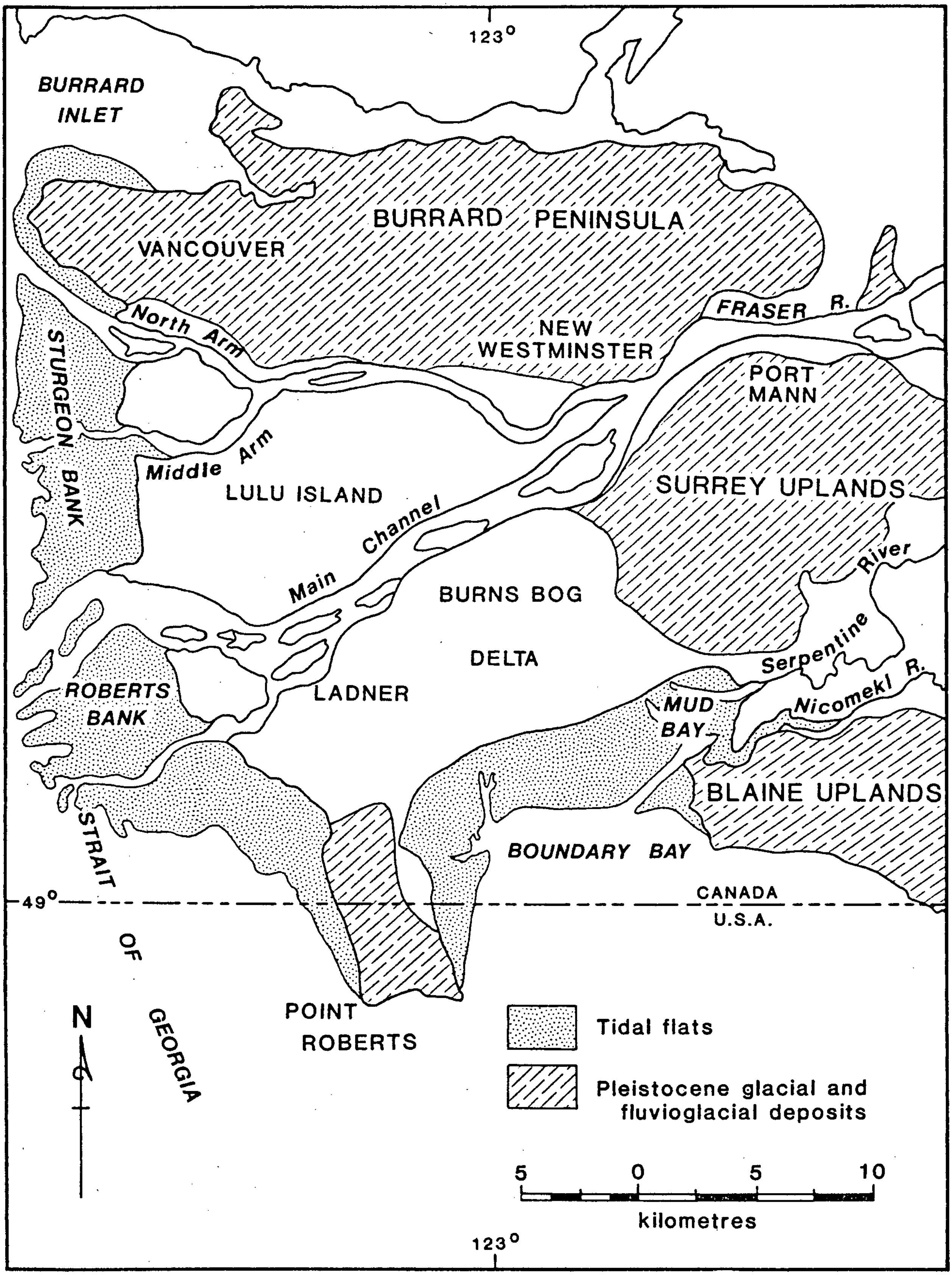


Figure 1. Map of the Fraser Delta area, showing the location of Boundary Bay.

remained unstudied.

The aim of this investigation was to interpret the development of the salt marsh, using biostratigraphy, sedimentology, and geochronology. Cores were collected and processed for palynomorphs, and pollen traps were monitored throughout the growing season over the study area, with the objective of relating horizontal facies on the present-day foreshore to vertical zones in the cores.

Regional Setting

The Fraser Delta extends 31 km west from New Westminster to the Strait of Georgia and south into Boundary Bay (Figure 1). The topography of the delta area is low, being only a few metres above mean sea level (Kellerhals and Murray, 1969); it is bounded on the north by the Burrard Peninsula and on the east by the Surrey Uplands, whilst the inactive southern part, Boundary Bay, is bounded on the southwest by Point Roberts, a former island of Pleistocene glacial and glaciofluvial sediments joined to the mainland by the development of the delta (Johnston, 1921a).

The delta meets the sea along a perimeter of more than 50 km, of which 37 km form the active western delta-front facing the Strait of Georgia between the Burrard Peninsula and Point Roberts. The abandoned part of the delta extends 13 km east from Point Roberts, facing south into Boundary Bay.

The Fraser Delta presents the form of a high grade delta (Johnston, 1921a) building out into the deep water of the Strait of Georgia, a large, semi-enclosed, marine waterway, separating Vancouver Island, on the southwest, from the mainland of British Columbia (Figure 1). The seaward front of the delta, being swept by strong northerly-trending flood tidal currents, has a smooth lobate outline, which Johnston (1921a) called arcuate. Four main distributary channels cross the Fraser Delta; the two major ones are known as the North Arm and the Main Channel. The sedimentation of the western delta-front has been described by Luternauer and Murray (1973).

The Fraser River is 1370 km long, rising on the western slope of the Rocky Mountains at 53°N, with a drainage basin of 234,000 km^2. The river is tidal up to Chilliwack, 105 km upstream, at low flows (November to March), but only up to Mission, 80 km upstream, during the remainder of the year (Hoos and Packman, 1974). The mean tidal range at the river mouth is 1.95 m, with a maximum of 4.6 m (Johnston, 1922). The highest water occurs during the May to July freshet. At low flows, a wedge of denser saline water extends upstream for 21 km beneath the less dense river water; the upstream extent of this wedge is reduced during the summer (Garrison *et al*., 1969).

The river contributes 2.0×10^7 m^3 of very fine sand and silt to the Strait of Georgia each year (Mathews and Shepard, 1962; Pharo and Barnes, 1976; Milliman, 1980). Much of the sediment of Boundary Bay, however, is derived from wave erosion of the Point Roberts Peninsula.

The seaward advance of the delta was estimated by Johnston (1921b) to be 3 m per year; its total volume is 8.92 x 10 m^3; its thickness is 214 m, and its subsidence rate is 0.012 m per decade (Mathews *et al*., 1970).

Geological History

The geological history of the Fraser Lowlands area is briefly summarized in Table 1. Johnston (1923), Luternauer (1974), and Blunden (1975) reviewed the geology of the Lower Fraser Valley, Johnston (1921a, 1921c), Armstrong (1956a, 1956b, 1957, 1960), Armstrong and Clague (1977), Clague (1976,1978), and Clague et al. (1980) have interpreted the Pleistocene history and surficial deposits, and Mathews et al. (1970) have described post-glacial crustal movements of the area.

About 8,000 years ago (Johnston, 1921a; Mathews, 1972; Blunden, 1973), the Fraser River began to fan out at New Westminster and form the modern delta. At New Westminster, the river has been contained in a valley 60 to 90 m wide throughout the formation of the modern delta (Johnston, 1921b).

As a consequence of the Sumas emergence (Table 1), peat bogs that are now 11 m below sea level developed on raised Fraser River alluvium (Mathews et al., 1970). These peats include those adjacent to the Port Mann Bridge (Figure 1), dated as 7,500 yrs B.P. (5-99, GSC-2), and the peat in Pitt Meadows Airport, being 8,290 yrs B.P. (GSC-229).

Sea level has remained near its present level for the past 5,500 years, with some minor fluctuations. A peat at 112th Street, Boundary Bay (Figure 2), dated as 4,350 yrs B.P. (GX-0781), occurs 1.8 m below the elevation at which such plants could presently grow (Kellerhals and Murray, 1969), indicating submergence at this location. This peat is discussed further in

Epoch	Age / Stage	Event / Unit	Deposits	Reference
HOLOCENE	5500 yrs.	Shoreline near present sea-level, minor fluctuations		(Mathews et al., 1970)
HOLOCENE	6000 - 9000	Land about 10m above present sea level		(Mathews et al., 1970)
— ? —				
PLEISTOCENE	Sumas Glaciation ~11500 yrs.	Sumas Emergence	glaciofluvial, channel, floodplain, deltaic, sand, gravel	(Mathews et al., 1970)
PLEISTOCENE	11500 - 12000	Pre-Sumas Submergence	fossiliferous marine sediments	(Mathews et al., 1970)
PLEISTOCENE	12000	Post-Vashon Emergence	terrestrial, deltaic sands and gravels (Armstrong, 1960)	(Mathews et al., 1970)
PLEISTOCENE	13000	Ice retreated		
PLEISTOCENE	Fraser Glaciation	Vashon Till	till, fluvioglacial, ice contact deposits, outwash, sand, gravel (Armstrong, 1977)	
PLEISTOCENE	Fraser Glaciation	Quadra Sand	cross stratified, well sorted white sand, minor gravel and silt, proglacial outwash (Armstrong, 1977; Clague, 1977)	
PLEISTOCENE	Olympia Nonglacial	Cowichan Head Formation	parallel bedded, marine, fluvial, estuarine silt, sand, gravel	
PLEISTOCENE		Semiahmoo & Dashwood Drifts	glaciomarine, glaciofluvial gravel, sand, clay, silt, till	
PLEISTOCENE		Highbury, Mapleguard Sediments	fluvial, marine, swamp deposits, sand, clay, silt (Fyles, 1963)	
~~				
PLIOCENE - MIOCENE		Boundary Bay Formation	sandstone, shale, volcanic ash, clay (Hopkins, 1966)	
UPPER EOCENE		Kitsilano Formation	conglomerate, sandstone, shale (Hopkins, 1969; Rouse, 1977)	
~~				
MID EOCENE - UPPER CRETACEOUS		Burrard Formation	conglomerate, sandstone, shale (Blunden, 1975; Crickmay and Pocock, 1963; Rouse et al., 1975)	
~~				
MID MESOZOIC		Coast Plutonic Complex emplaced		

Table 1. Summary of the geological history of the Fraser Lowlands.

Chapter 3.

Peat bogs developed on the surface of the delta, in depressions formed by former channels, and cover one third of the subaerial delta surface; other surficial deposits include glacial drift, lacustrine, deltaic, and fluvial sands and silts, and saltmarsh deposits (Armstrong, 1956, 1957, 1960, 1979, 1980). In Burns Bog, a short salt marsh phase developed above delta front silty sands commencing at 4125±110 yrs B.P. (Hebda, 1977). Peats forming Lulu Island bogs commenced forming 4685±95 years B.P. (Teledyne, 1-11, 742) and are being studied by Styan, 1981.

The Study Area

Boundary Bay may be described as a headland-bay beach (Yasso, 1965, LeBlond, 1979); it is 15 km long and 4 km wide, with a surface area of 61 km^2 (Figure 2). The Bay is protected from westerly and southwesterly winds by the Point Roberts Peninsula. The Serpentine and Nicomekl Rivers flow into the northeast corner, known as Mud Bay, and small, ephemeral streams enter it from the west. The area has a modified West Coast maritime climate, with mild, wet winters and dry, warm, bright summers. The climate is described as a Koeppen Csb Mediterranean-type climate (Hoos and Packman, 1974). Meteorological records taken at Ladner, 5 km northwest of the 64th Street area, show an average of 903 mm of precipitation a year, including 34 cm of snow; most rain falls in December and least in July. The annual average temperature is 9.4°C, the July mean

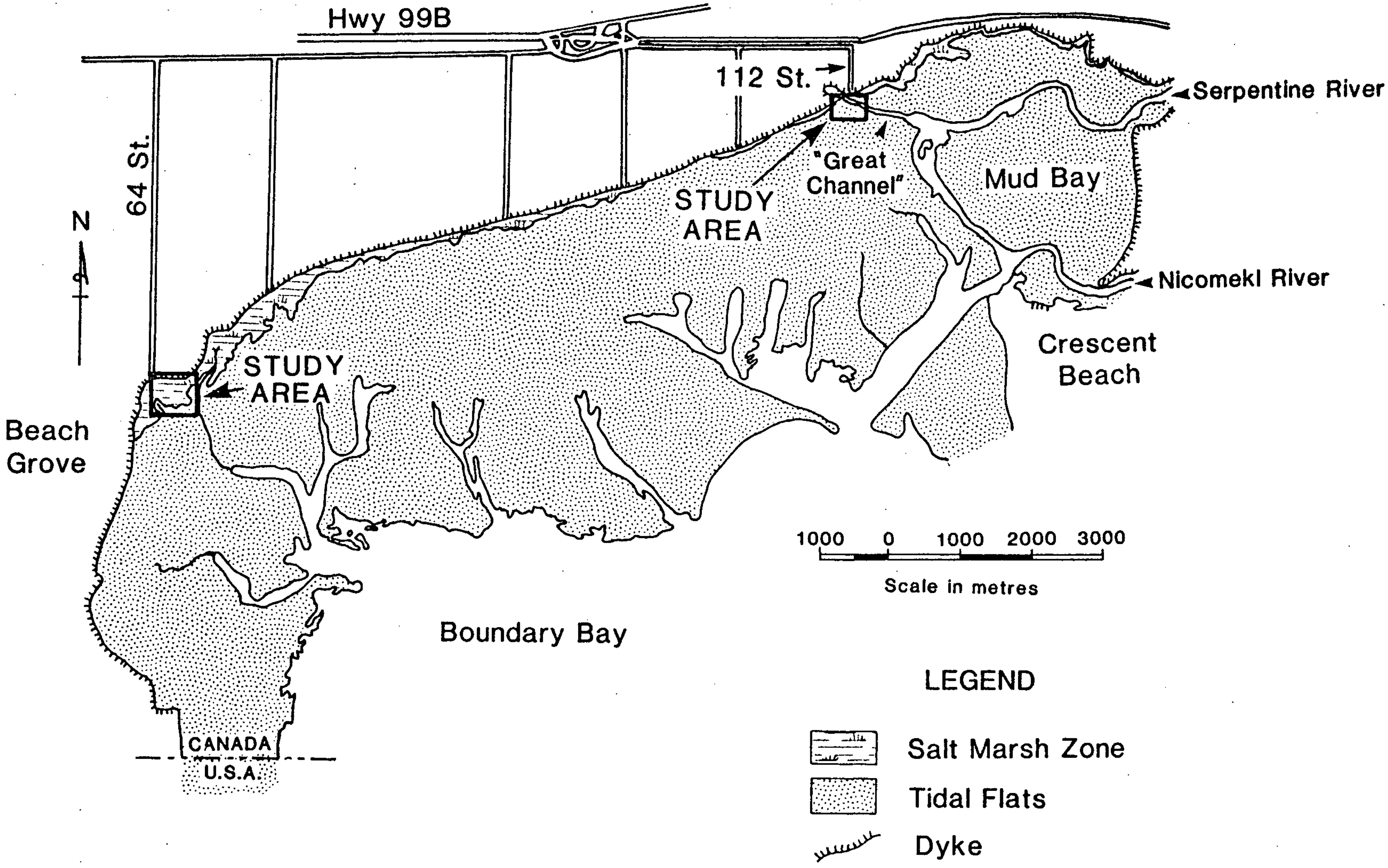


Figure 2. Map of Boundary Bay showing locations of the study areas (modified after Swinbanks, 1979).

being 16.7°C and the January mean, 2.2°C. (British Columbia Department of Agriculture, 1971). Prevailing winds come from the east and southeast, and humidity is high throughout the year (Hoos and Packman, 1974).

The tides in Boundary Bay are a mixed semidiurnal type, with two high and two low waters each day. Successive high and low waters are of different heights (Weir, 1960). Tides enter the Bay from the south, the flood tide being more concentrated on the east side and the ebb more concentrated on the west side (Weir, 1960). The highest mean spring tidal range is about 3 m, with the mean tidal range being 2.7 m and the mean neap tidal range being 1.5 m (Weir, 1960). The water in the Bay is clear, and has a salinity of 24 to 29 permil, similar to that of the Strait of Georgia (Swinbanks, 1979).

The surface sediments in the Bay have been described by Kellerhals and Murray (1969) and Swinbanks (1979), and include gravel, sand, silty sand, mud, peat, and accumulations of shells and driftwood. The grain size of the surface sediments in most localities varies little, however, being mainly very fine to fine sand which shows a gradual shoreward fining trend (Swinbanks, 1979).

Detrital sediments in Boundary Bay come largely from the erosion of the Pleistocene cliffs at Point Roberts; lesser amounts are derived from the erosion of the salt marsh at Mud Bay. The Serpentine and Nicomekl Rivers bring some silt and clay into the eastern part of the Bay. Sediment is transported in the Bay by longshore drift (Swinbanks, 1979). The tidal flats are drained by creeks.

The bedrock beneath Boundary Bay is the Pliocene/Miocene Boundary Bay Formation. In a 1250 m deep well (Boundary Bay Well No. 3 (Johnston, 1923)), 700 m of Pleistocene and Recent deposits were penetrated, with the underlying sediments consisting of poorly consolidated sands, shales, lignites, conglomerates, and gravels of Pliocene-Miocene age (Hopkins, 1966).

Prior to the construction of the dykes, the low-lying land adjacent to Boundary Bay was frequently inundated by winter and spring high tides, sometimes associated with the Fraser River freshet. Land was commonly under water for up to six months of the year (Howie and Scholfield, 1914, in Taylor, 1958). Farmers built dykes around their own land, but following the Great Flood in 1894, which was associated with the Fraser River freshet in May and June and which covered the land with 0.6 to 1 m of water, Delta Municipality undertook dyking (Taylor 1958; Terris 1973; Ladner 1979). The first dyke was built along Boundary Bay in 1895, and the dykes were later strengthened and heightened in 1948, following the Fraser Valley flood.

The Fraser River Delta is in the wetter subzone of the Coastal Douglas-Fir Biogeoclimatic zone of British Columbia (Krajina, 1969); this vegetation is present on upland areas. Some natural vegetation had been cleared for farming, by beavers, and by fire (North _et al_., 1979) prior to 1858, when the land was first surveyed. Between 1858 and 1880, the drift ridges were forested; Burrard Peninsula and the Surrey Uplands possessed a vegetation of coniferous, scrub, and deciduous forest, whilst the Blaine Uplands and Point Roberts Peninsula were vegetated by coniferous and lesser amounts of deciduous forest. The lowlands of the delta were dominantly grass prairie, with some trees on higher areas and shrubs and mosses covering the large bogs. Some salt marsh development occurred around Boundary Bay, extending inland from the sea. The seaward extent of the salt marsh is not shown on early maps.

Radiocarbon dates suggest that the salt marsh at 64th Street was initiated about 345±75 years B.P. (Teledyne, 1-11, 764). It may have extended northwards from the Bay, but being a surficial deposit, would have been ploughed and destroyed when farming began.

The tidal flats at Boundary Bay have been subdivided into different zones by previous workers. Kellerhals and Murray (1969) recognized four main sedimentologic-hydrologic divisions of the tidal flats, each possessing distinct drainage patterns, sedimentary structures, and floral and faunal assemblages. Swinbanks (1979) revised their zonation, establishing five zones delimited by elevation and exposure (in relation to critical tide levels), each with a distinctive flora and fauna. The main points of each scheme are summarized on Figure 3.

This study concentrates on a salt marsh which has developed on the tidal flats at 64th Street and is bounded landward by a dyke (Figure 2). The salt marsh is up to 600 m wide in the west of the Bay, but becomes very narrow and locally disappears to the east (Kellerhals and Murray, 1969). The marsh to the west is thought to be prograding over the tidal flats, as seen by

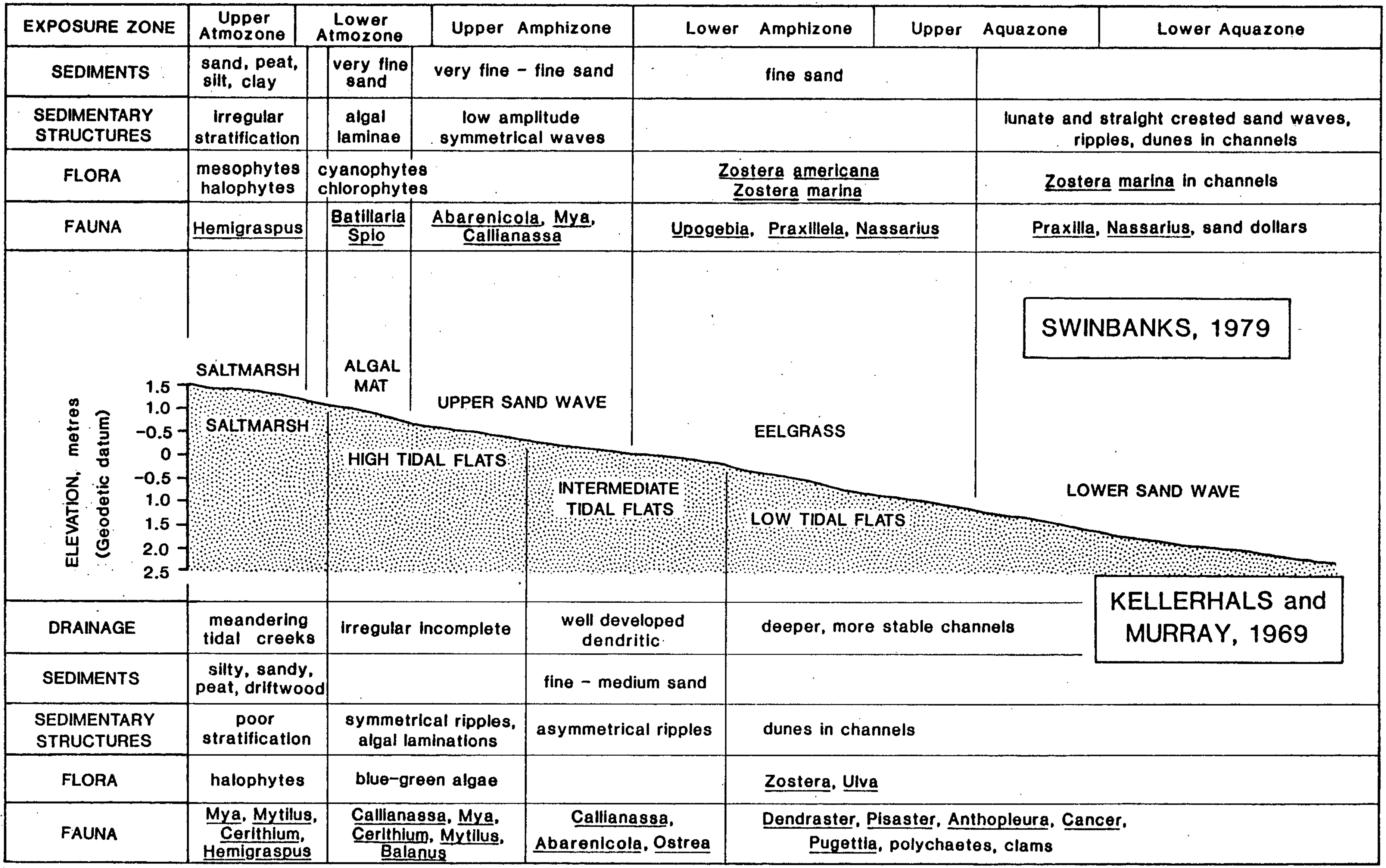


Figure 3. Summary of the subdivisions of the Boundary Bay tidal flats, according to Swinbanks and Kellerhals and Murray.

former beach ridges consisting of logs being overgrown by vegetation, whereas in the east, cliffs at the seaward edge of the marsh and the presence of a partly buried older peat indicates erosion and redeposition; a 1200 m recession in the salt marsh since 4350±100 years B.P. (GX-0781) was calculated by Kellerhals and Murray (1968) based on the position of present day salt marshes relative to the shoreline.

The salt marsh developing today in the west part of Boundary Bay appears to be a typical simple Pacific coast salt marsh (Chapman, 1960; MacDonald and Barbour, 1974). Most salt marshes decrease in height from the land towards the sea, accompanied by changes in the vegetation. The lower part of the marsh is subject to frequent tidal inundations, whilst the upper part is rarely flooded. The salt marsh at 64th Street appears to conform to these specifications.

CHAPTER 2: METHODS

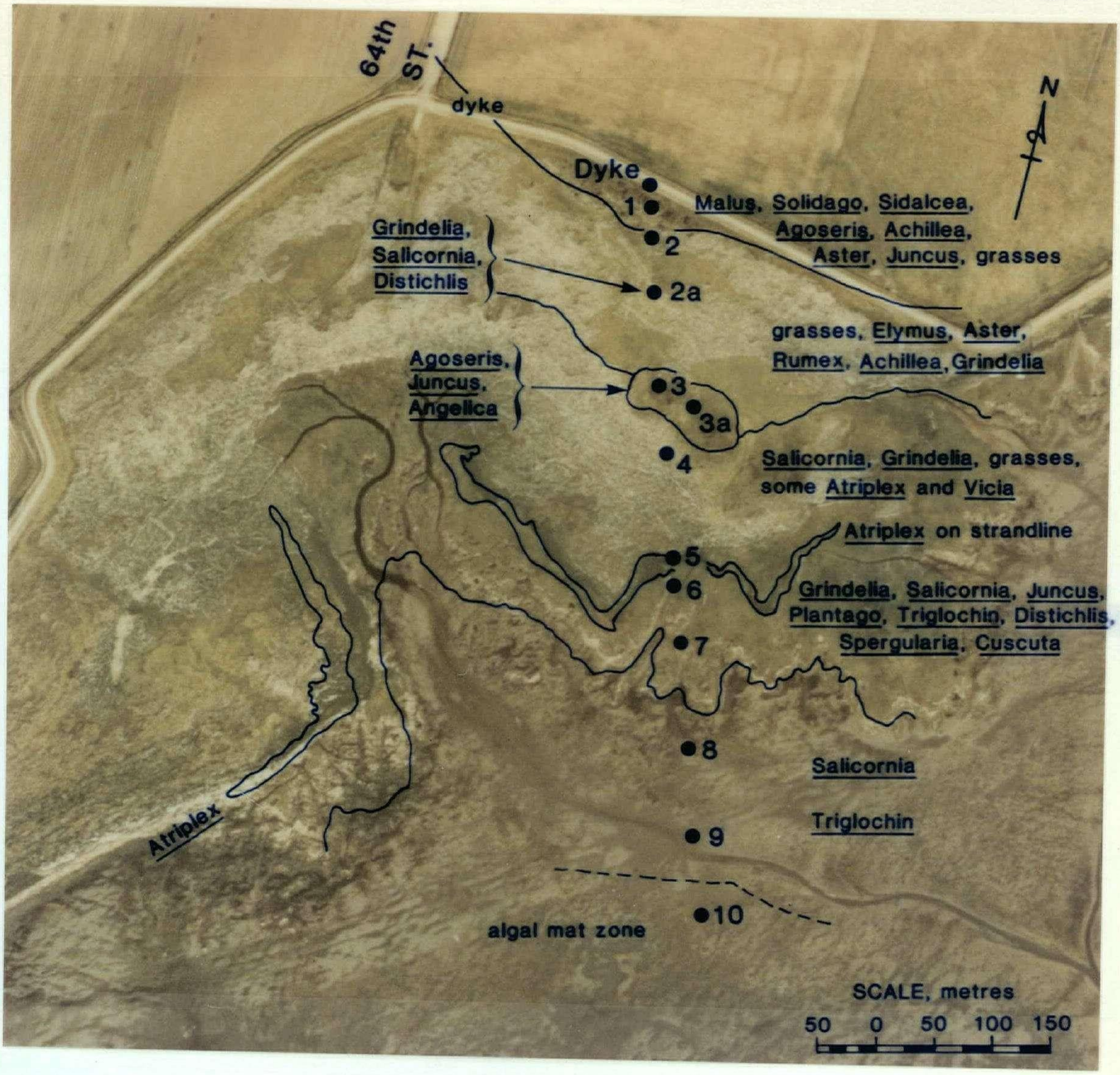
Field Methods

A series of eleven cores was obtained from the salt marsh at 64th Street (Figure 4) and three from 112th Street (Figure 5). Coring with a Hiller corer, a vibrocorer, and a truck-mounted corer were unsuccessfully tried. Digging a large hole and sampling the sides proved to be the most successful method. Samples were collected in 30 cm lengths and were wrapped in aluminum foil. The upper, friable peats were sub-sampled at 5 cm intervals and put into plastic bags if they were very unconsolidated. Samples for radiocarbon dating were wrapped twice in aluminum foil, placed in plastic bags, and frozen upon returning to the laboratory. Twelve pollen traps were monitored from 1.5.80 to 30.11.80 at various locations over the salt marsh at 64th Street (Figure 4). Cores were obtained from areas adjacent to the pollen traps. Glass jars, with a thin film of glycerine in the bottom to prevent grains being blown out of the jars and covered with a 1.42 mm screen, were sunk in the ground so that only 2 cm protruded. The jars were emptied regularly.

Modern pollen was collected from the various species (Table 2) on the salt marsh, the species being identified by use of Hitchcock and Cronquist (1973).

Figure 4. The salt marsh at 64th Street, showing station locations and the vegetation zones.

Figure 5. Map showing location of the cores obtained near 112th Street.


64th ST.
dyke
N
Dyke
1
2
2a
Malus, Solidago, Sidalcea,
Agoseris, Achillea,
Aster, Juncus, grasses
Grindelia,
Salicornia,
Distichlis
grasses, Elymus, Aster,
Rumex, Achillea, Grindelia
Agoseris,
Juncus,
Angelica
3
3a
4
Salicornia, Grindelia, grasses,
some Atriplex and Vicia
Atriplex on strandline
5
6
7
Grindelia, Salicornia, Juncus,
Plantago, Triglochin, Distichlis,
Spergularia, Cuscuta
8
Salicornia
9
Triglochin
Atriplex
10
algal mat zone
SCALE, metres
50 0 50 100 150


112th St.
N
Dyke
"Great Channel"
11
12
13
SCALE, metres
50 0 50 100

Table 2. Vegetation found at 64th Street.

CARYOPHYLLACEAE	
Spergularia marina L.	sandspurry
CHENOPODIACEAE	
Atriplex patula L.	orache, greasewood, saltbush
Salicornia virginica L.	samphire, glasswort, saltwort
COMPOSITAE	
Achillea millefolium L.	yarrow, milfoil
Agoseris sp. Raf.	false dandelion
Aster subspicatus Nees.	aster
Grindelia integrifolia D.C.	gumweed, resinweed
Solidago sp. L.	goldenrod
CUSCUTACEAE	
Cuscuta salina Engelm.	saltmarsh dodder
GRAMINEAE	
Agropyron sp. Gaertn.	quackgrass
Agrostis sp. L.	bentgrass
Distichlis spicata L.	saltgrass
Elymus mollis Trin.	dune grass, lime grass
Puccinellia sp. Parl.	alkali grass
JUNCACEAE	
Juncus balticus Willd.	rush
JUNCAGINACEAE	
Triglochin maritimum L.	arrow grass
LEGUMINOSAE	
Vicia sativa L.	common vetch
MALVACEAE	
Sidalcea hendersoni Wats.	marsh mallow
PLANTAGINACEAE	
Plantago maritima L.	seaside plantain
POLYGONACEAE	
Rumex crispus L.	curled dock, sorrel
ROSACEAE	
Malus fusca Raf.	Pacific wild crabapple
UMBELLIFEREAE	
Angelica lucida L.	angelica
ZOSTERACEAE	
Zostera marina L.	eelgrass
Zostera nana Roth.	eelgrass

<u>Laboratory Methods</u>

The cores were divided into 5 cm intervals and 10 cm^3 of each interval was taken for palynological processing. Mechanical maceration was not required, as the sediments were unconsolidated.

The dominantly sandy sediments were processed differently from the peaty samples. A drop of cold HCl was added to the sandy sediments to test for the presence of calcium carbonate; none was detected in any of the samples. After washing in water, the sample was put into 300 ml of 48% HF in a teflon beaker and magnetically stirred for twelve hours to dissolve silicates. After letting the sediment settle, the HF was siphoned off, and the sample washed three times in water. The sample was then boiled in 6 M HCl to dissolve ferric compounds. After washing, a known number of tablets containing <u>Lycopodium clavatum</u>* was added to act as an internal standard for calculating absolute frequencies (Stockmarr, 1971; Hebda, 1977). The tablets were dispersed in HCl prior to being added to the samples. Acetolysis was performed, using a mixture of nine parts 97% acetic anhydride and one part 18 M sulphuric acid, for ten minutes, to remove cellulose and other organic material. The samples were then oxidized in 5% sodium hypochlorite, if necessary, and screened through a 10 μm sieve to remove fine black mineral matter which persisted in the samples. They were then

*Tablets obtained from Dr. J. Stockmarr, Geological Survey of Denmark. These are no longer available from this source, but may be obtained from Dr. B.E. Berglund, Department of Quaternary Geology, Tormavagen-13, Lund, Sweden.

screened through a 100 m sieve, and slides containing the coarser and finer fractions were made, using "Kleermount Toluene Solution" as a mounting medium. This was done as the coarse organic remains frequently obscured the pollen and spores. The samples were stained in a 0.05% safranin solution and additional slides made.

The peats and peaty sediments were first boiled in 5% KOH for ten minutes to remove lignin and woody tissue, and then were screened through a 1.42 mm sieve. HCl and HF were used if mineral matter was present, and the process continued as outlined above for sandy samples.

A minimum of 200 pollen grains per sample was counted in two traverses over the slide, and pollen diagrams constructed for the cores. The total number of pollen grains in a sample was calculated using _Lycopodium_ as an internal standard, and the following formula (Stockmarr, 1971):

$$\frac{\text{No. of } \underline{\text{Lycopodium}} \text{ spores added (10,850 per tablet)} \times \text{No. of pollen grains counted}}{\text{No. of } \underline{\text{Lycopodium}} \text{ spores counted}}$$

= total number of pollen grains in a sample

The trapped matter obtained from the pollen traps was washed in water, treated with 48% HF, and acetolized for three minutes. Slides were then made, using the same procedure as for the core samples. If much mineral matter was present, such as in those jars from the intertidal zones, they were boiled in 6 M HCl after HF, sieved, and bleached. Finally, $ZnBr_2$ solution, with a density of 2.4 g cm^{-3} was used to float organics from the mineral matter.

The modern pollen were processed using acetolysis and microscope slides of each species prepared for identification of pollen recovered from the cores. Selected pollen grains were examined with the Scanning Electron Microscope (Figures 6, 7 and 8). A modern pollen and spore collection, prepared from Pacific Northwest species, was used to identify remaining palynomorphs.

Figure 6. *Agoseris* sp. S.E.M. Photograph.
(scale bar represents 2μm).

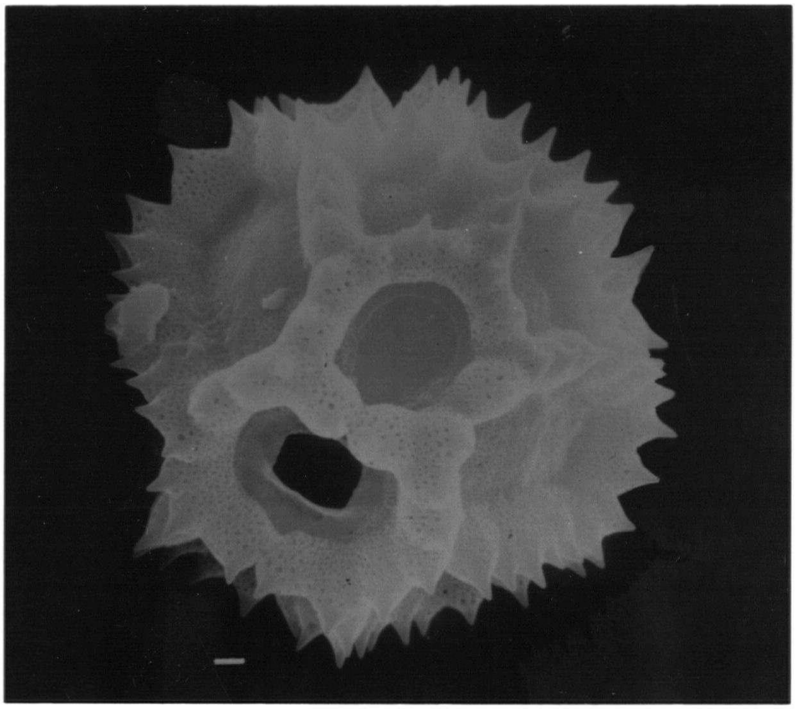
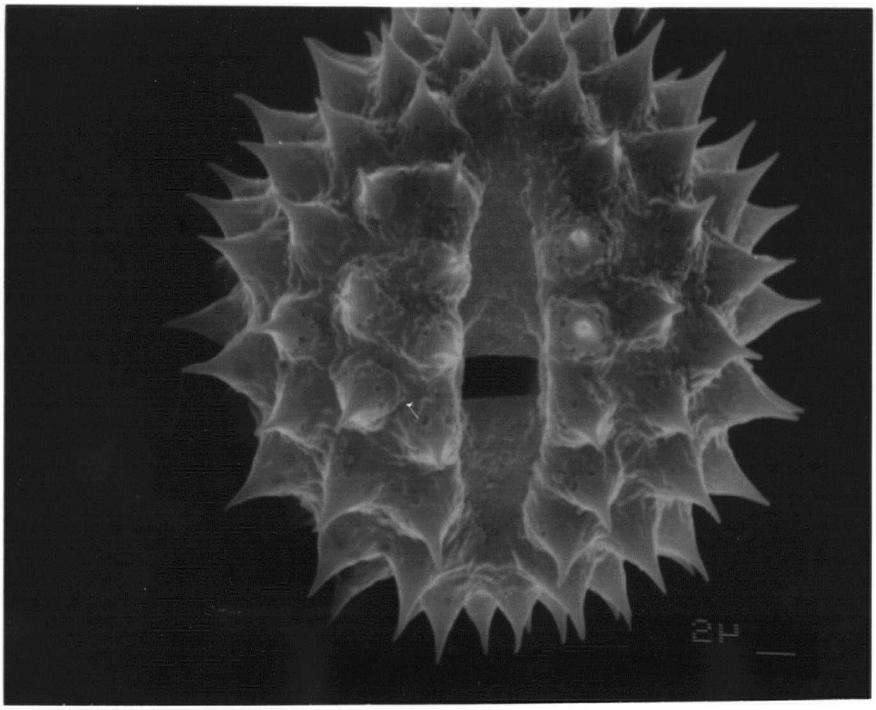


Figure 7. Grindelia integrifolia. S.E.M. Photograph.

Figure 8. Aster subspicatus. S.E.M. Photograph.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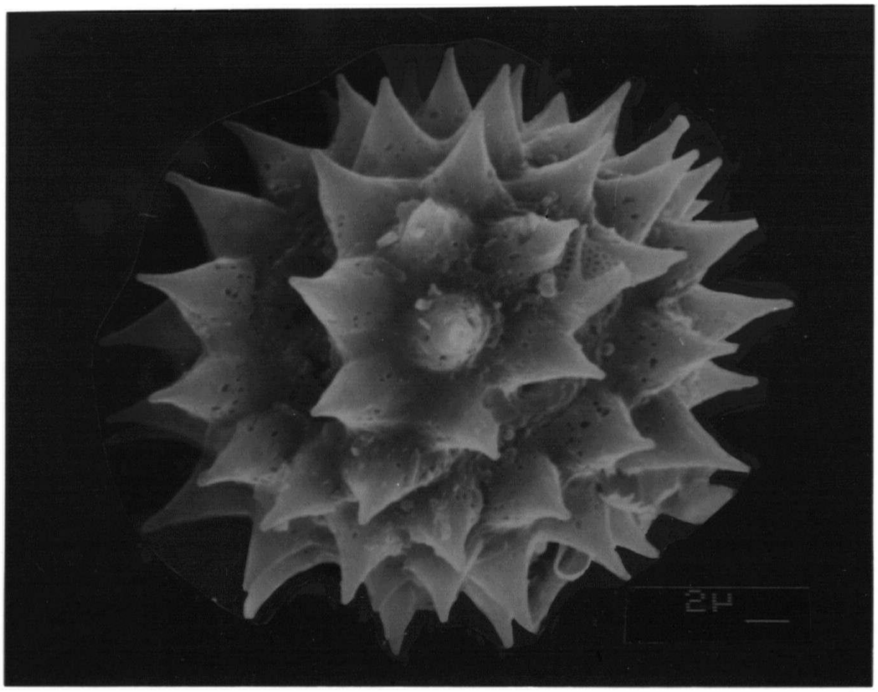

2μ

Pollen and Spore Identification

The two common salt marsh chenopods, Salicornia virginica and Atriplex patula (Figure 9) both possess spheroidal, periporate pollen ranging from 23 to 27 μm in diameter. The main distinguishing characteristic is pore diameter, which is greater than 2 μm in Salicornia virginica, but less than 2 μm in Atriplex patula, averaging at 1.6 μm. Also, the interpore distance is 4 to 6 μm in Salicornia virginica compared to 3 to 7 μm in Atriplex patula. Furthermore, the exine of Salicornia virginica is thinner, being 1.2 to 1.5 μm, with relatively indistinct columellae, whereas the wall of Atriplex patula is 1.9 to 2.1 μm thick, with a moderate columellate structure.

The pollen of Cuscuta salina (Cuscutaceae) and Spergularia marina (Caryophyllaceae) are quite similar, being tricolpate with reticulate sculpture (Figure 9). They are distinguishable on the basis of size; C. salina is larger (22 to 28 μm; average 23.8 μm) than S. marina (21 to 26 μm; average 22.6 μm). A few stephanocolpate S. marina grains were also observed.

Gramineae pollen, being spheroidal and monoporate, were studied from many grasses, but no distinguishing criteria could be found in most. Pollen of Elymus mollis (Figure 9), however, were identifiable by size, grains being 45 to 62 μm in diameter (average 51.5 μm), with a dense granulate ornamentation. The remaining grass pollen are less than 42 μm in diameter, and were grouped in the counts.

Sidalcea hendersoni (Malvaceae) has distinctive pollen

Figure 9. Selected pollen grains from the salt marsh vegetation.

a. *Salicornia virginica* (x 1000).

b. *Atriplex patula* (x 1000).

c. *Cuscuta salina* (x 1000).

d. *Spergularia marina* (x 1000).

e. *Aster subspicatus* (x 1000).

f. *Solidago* sp. (x 1000).

g. *Achillea millefolium* (x 1000).

h. *Grindelia integrifolia* (x 1000).

i. *Elymus mollis* (x 1000).

j. *Distichlis spicata* (x 1000).

k. *Plantago maritima* (x 1000).

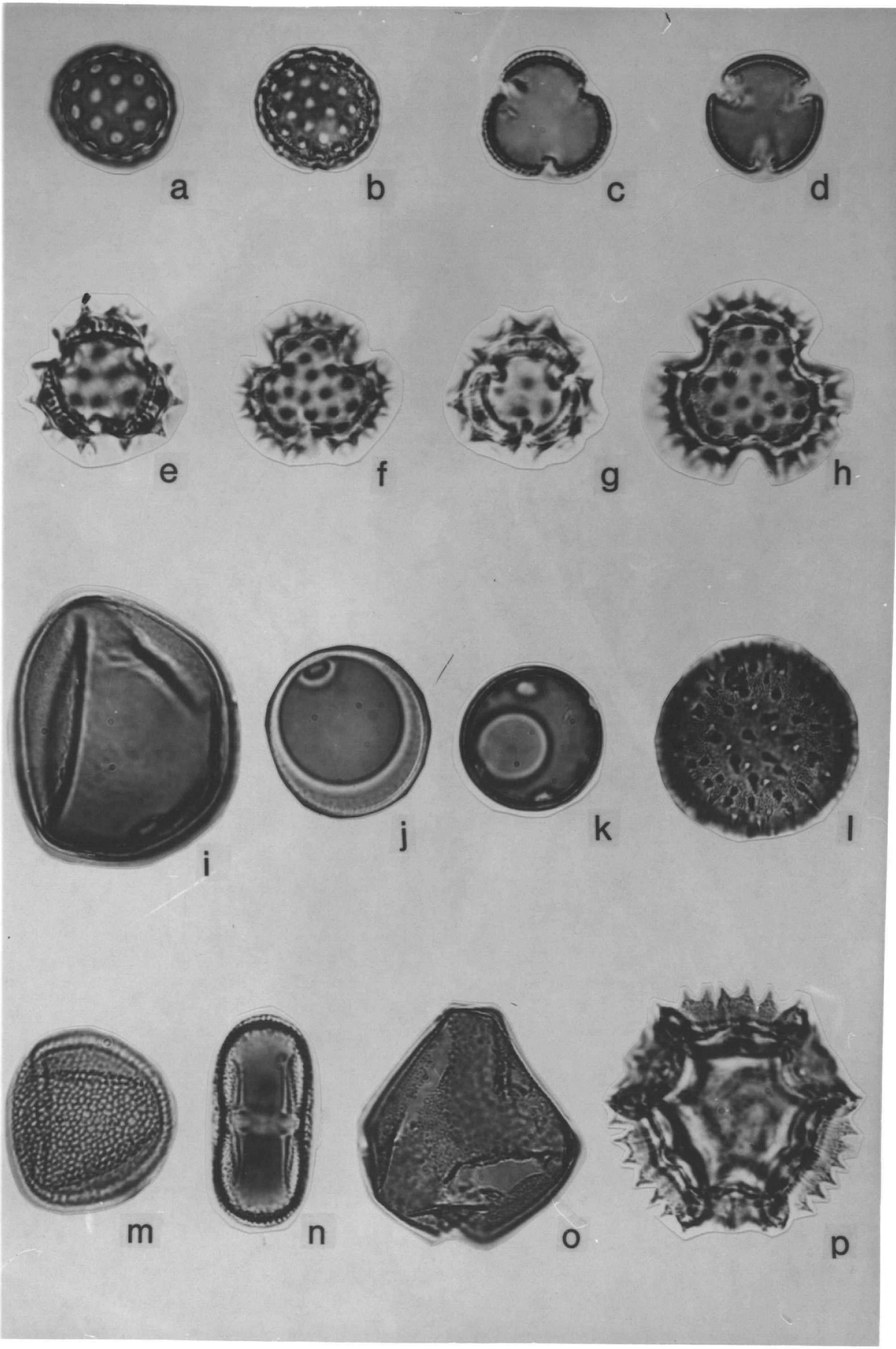
l. *Sidalcea hendersoni* (x 500).

m. *Triglochin maritimum* (x 1000).

n. *Angelica lucida* (x 1000).

o. *Juncus balticus* (x 1000).

p. *Agoseris* sp. (x 1000).


a
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(Figure 9); grains are spheroidal, periporate, echinate, and 77 to 90 μm in diameter (average 84.5 μm), including spines that are 7 to 8 μm long.

Identification of the Compositae was difficult, as all the pollen grains are tricolporate and echinate. Agoseris sp. grains (Figures 6 and 9) range from 40 to 45 μm in diameter (average 43.8 μm), and the exine consists of depressions (lacunae) separated by high ridges (muri) with supra-tectal spines. The other composite pollen, of Grindelia integrifolia, Aster subspicatus, Solidago sp., and Achillea millefolium are spherical and echinate. G. integrifolia can be distinguished from the others by its larger size, averaging 34 μm, including spines (Figures 7 and 9). The columellae extend into the spines for about 1 μm and beads are present around the rim of the pore. Aster is 28 to 30 μm in diameter, including spines. The exine is columellate and reticulate (Figures 8 and 9). Solidago and Achillea were grouped, as no distinguishing criteria were observed; also, separation of these two was not felt to be critical, because they occur together on the most emergent part of the salt marsh. Both pollen have a thick, heavy exine and are 27 to 30 μm in diameter.

CHAPTER 3: RESULTS

The Salt Marsh at 64th Street

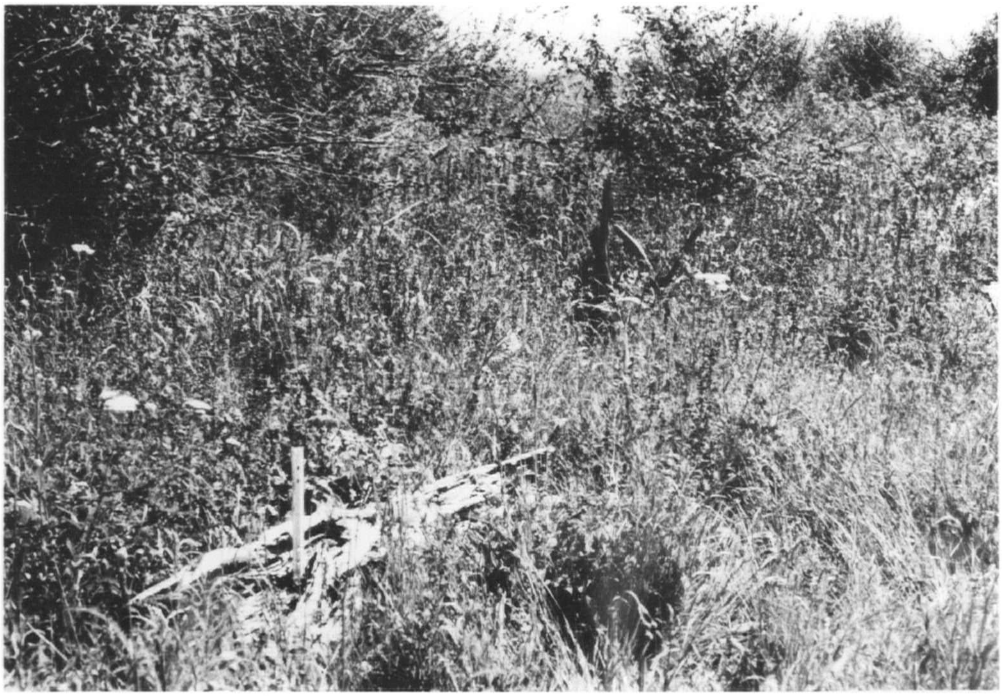
Distinctive changes in the vegetation of the salt marsh can be observed in a seaward direction from the dyke. The upper, emergent part of the marsh has been colonized by mesophytes, whereas halophytes dominate the vegetation in the lower, submergent part. The zonation of the vegetation is due to changes in elevation rather than time (Figure 4).

Distribution of Vegetation

The most landward part of the salt marsh near the dyke possesses a vegetation of *Malus fusca*, *Solidago* sp., *Sidalcea hendersoni*, *Agoseris* sp., *Aster subspicatus*, *Achillea millefolium*, *Juncus balticus*, and grasses (Figure 10). *Solidago* sp. and *Juncus balticus* are not present at Station 1 - they occur only closer to the dyke. Around Station 1, isolated plants of *Angelica lucida* and *Rumex crispus* are found. *Malus fusca*, *Sidalcea hendersoni*, and *Agoseris* sp. do not occur seaward of this zone, except for a small patch of *Agoseris* sp., which occurs with *Angelica lucida* at Station 3a. Grasses dominate the vegetation at Station 2, including isolated patches of *Elymus mollis*. A small channel (in which Station 2a was located), containing driftwood, possesses a vegetation that contrasts with the adjacent areas (Figures 4 and 11). In the channel,the main species are *Grindelia integrifolia* and *Distichlis spicata*, with lesser amounts of *Salicornia virginica*,

Figure 10. The most landward part of the salt marsh near the dyke (scale is 30 cm).

Figure 11. The channel by Station 2a, in which *Distichlis spicata*, *Grindelia integrifolia* and *Salicornia virginica* grow.



whilst around the channel the main plants are Aster subspicatus, Rumex crispus, Achillea millefolium, with sporadic Grindelia integrifolia, Elymus mollis, and other grasses. This channel filled with seawater in the winter of 1980-1981, and the vegetation in it represents a less emergent zone compared to the surrounding vegetation in that the plants can tolerate periodic submergences by marine waters.

At Station 3a, there is a localized circular zone of Juncus balticus, Angelica lucida, and Agoseris sp. The reason for this zone developing here is unknown, but may be related to a topographic high in the underlying silts. Seaward of Station 3 is a zone covered in driftwood washed in by storms; the vegetation is less diverse than at Stations 1 and 2. Aster subspicatus, Achillea millefolium, Elymus mollis, Rumex crispus, Angelica lucida, and Agoseris sp. do not grow seaward of this point. Salicornia virginica, Grindelia integrifolia, and grasses also grow here, with occasional plants of Atriplex patula and Vicia sativa. Cuscuta salina, the saltmarsh dodder, occurs as a parasite on host Salicornia plants. This zone is quite extensive, ending abruptly seaward at the upper limit of the strandline; beyond the strandline there are no logs, but storm litter has accumulated to form thick mats of eelgrass mixed with algae (Figure 12). The strandline marks the transition between the upper, emergent, more established marsh, with a thicker peat, and the lower, submergent marsh with a thin cover of organic rich sand. Along the strandline, Atriplex patula grows luxuriantly amongst the eelgrass in a zone about 3 m wide (Figure 13) Atriplex is often found growing along the strandline as its

Figure 12. Eelgrass, washed in by storms, around *Triglochin maritimum* (scale is 30 cm).

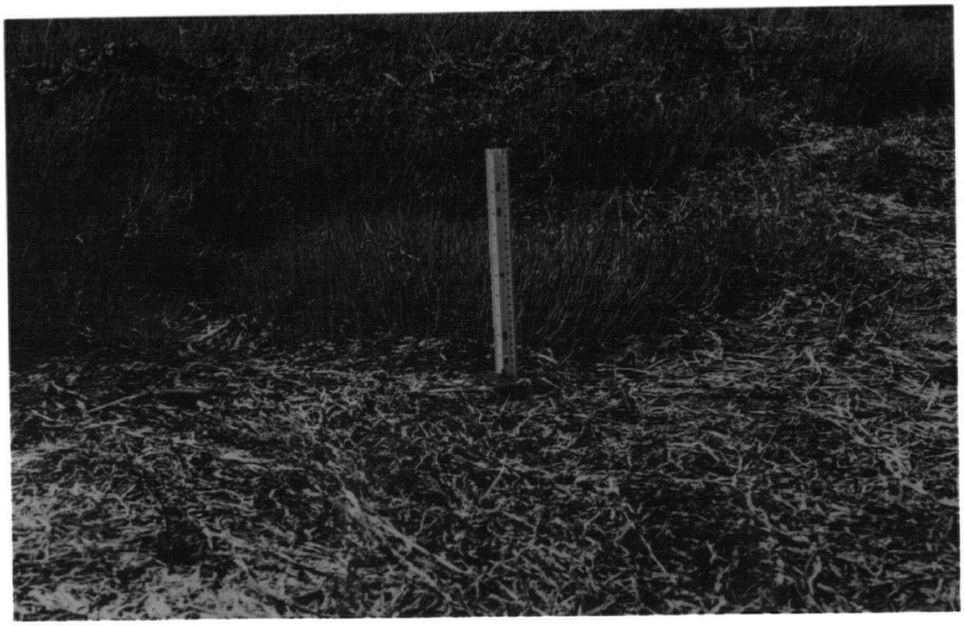
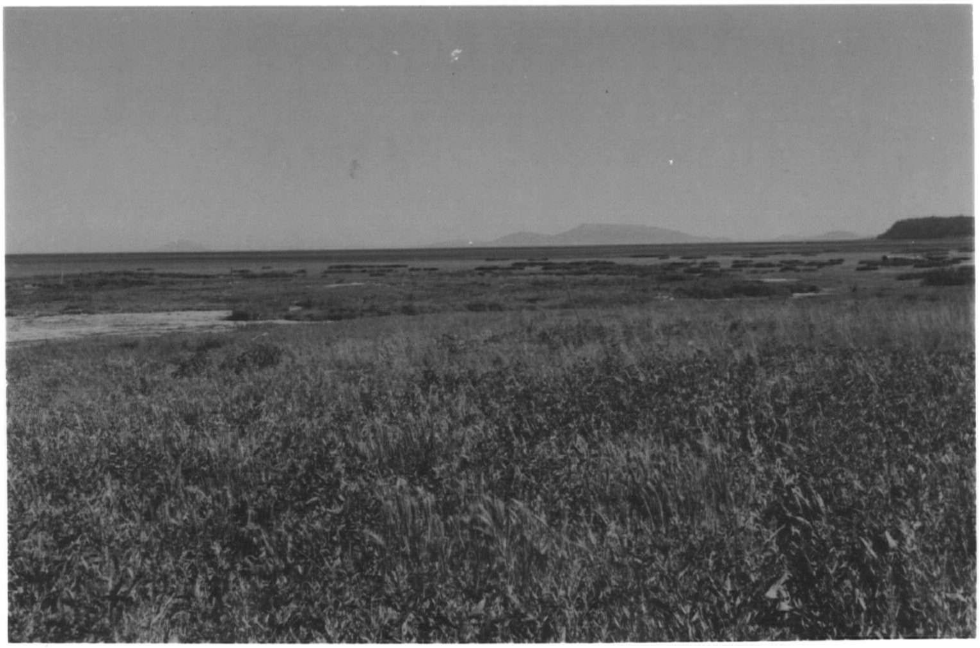


Figure 13. *Atriplex patula* growing along the strandline. The submergent marsh can be seen seaward of this zone.

Figure 14. Halophyte hummocks beyond the seaward edge of the continuous marsh.



seeds are trapped in the tidal litter (Chapman, 1976; Ranwell, 1972); Hulme (1957, in Ranwell, 1972) describes the colonization of this zone by Atriplex on the foreshore at Longriddry, East Lothian, Scotland. A similar process is envisaged to occur in Boundary Bay.

The zone seaward of this narrow strandline is colonized mainly by the halophytes Salicornia virginica, Triglochin maritimum, Spergularia marina, and Cuscuta salina. In the proximal part of the zone, these are associated with Distichlis spicata, Plantago maritima, and Grindelia integrifolia, but seawards Salicornia virginica and Triglochin maritimum persist alone. Cuscuta salina was found on Salicornia plants only seaward of Station 4.

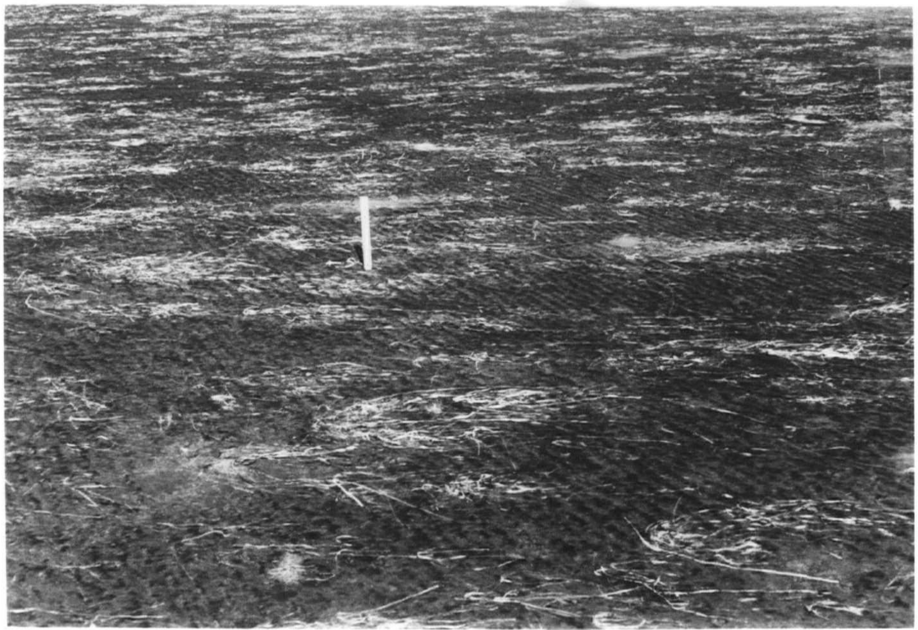
The pioneer plants of the marsh appear to be Salicornia virginica and Triglochin maritimum; isolated hummocks colonized by these halophytes (Figure 14) are found extending outward from the seaward edge of the continuous marsh where it encroaches onto the high tidal flats. The high tidal flats are covered by extensive algal mats, which stabilize ripples and bind washed-in eelgrass blades (Figures 15 and 16).

Distribution of Modern Pollen

Pollen assemblages, collected at various locations over the salt marsh (Figure 17), reflect the general zonation of vegetation in the marsh (Figure 4), but there are some discrepancies. The nature of the vegetation, changing from the diverse assemblage of mesophytes (Aster, Solidago, Achillea, Sidalcea,

Figure 15. Algal mats stabilizing ripples on the high tidal flats (scale is 30 cm).

Figure 16. Algal mats binding washed-in eelgrass blades.



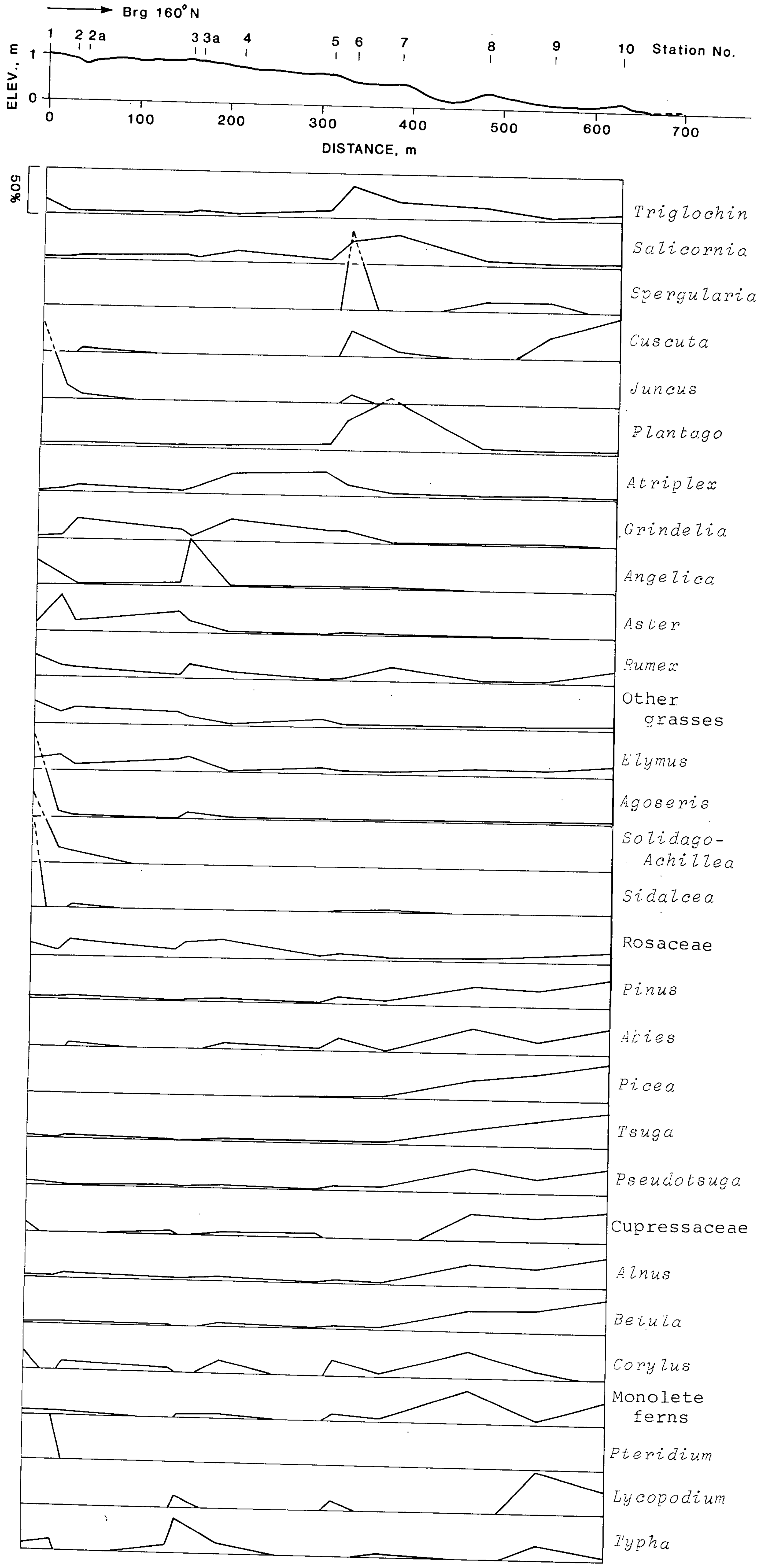


Figure 17. Pollen assemblages collected at the Stations over the transect on the salt marsh at 64th Street from May to November, 1980.

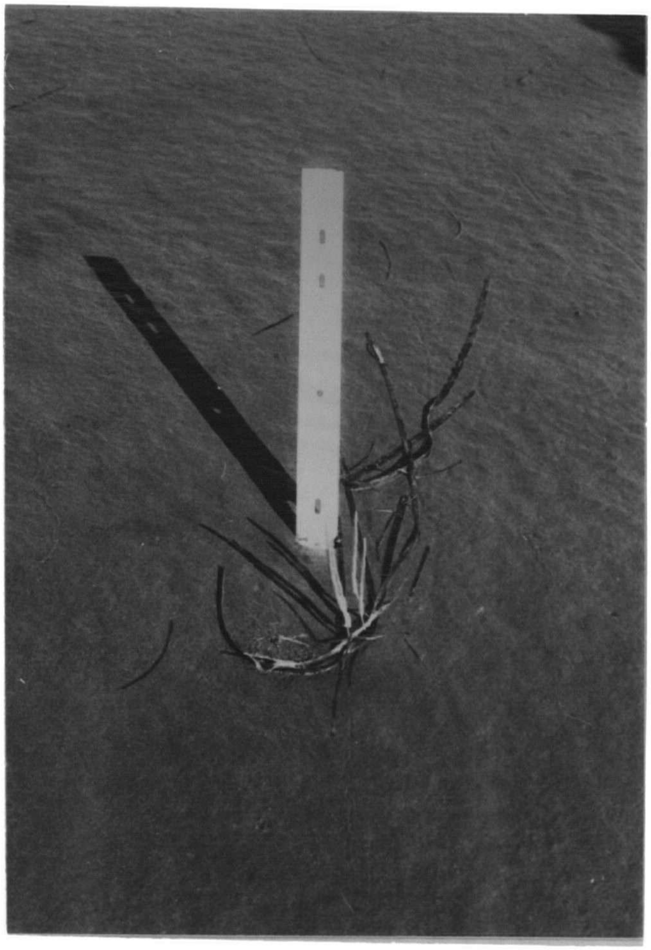
Agoseris, Angelica) at the inner, most elevated margin of the marsh, to a zone dominated by grasses at Station 2, to the Atriplex-colonized strandline at Station 5, and finally to Salicornia and Triglochin at the lowest, seaward edge of the salt marsh, can be clearly seen in Figure 17. The channel, with Grindelia at Station 2a, and the Angelica-Agoseris zone at Station 3a are visible. However, the dispersal of pollen by wind and water must be considered. Atriplex appears to be more widespread than its source zone, as do Elymus, Triglochin, and Rumex. The distribution of arboreal pollen shows that they have been dispersed by both wind and water; wind is more important in the upper marsh and water in the lower marsh. High concentrations of arboreal pollen, representing coast forest species, at the seaward edge of the marsh are due to these pollen being abundant in the seawater of the Strait of Georgia. In addition, some were possibly transported into the Bay by the Serpentine and Nicomekl Rivers and other smaller streams. A marked decrease in coast forest pollen landward of Station 6 is attributed to a lack of frequent submergence of the salt marsh by marine waters. The Rosaceae pollen may have been derived largely from Malus fusca growing at the inner margin of the marsh.

Formation of the Salt Marsh

The seaward edge of the salt marsh consists of irregular hummocks, 30-60 cm high, which have been colonized by halophytes (Figure 14); the first subaerial colonists of the sandy tidal flats are Salicornia virginica and Triglochin maritimum (Figures 18 and 19). Kellerhals and Murray (1969) state that the devel-

Figure 18. Pioneer Salicornia virginica on the high tidal flats (scale is 30 cm).

Figure 19. Small Triglochin maritimum hummock (scale is 30 cm).



opment of the hummocks is related to large amounts of algal debris and eelgrass being rafted into the area in the fall; these are covered by sand during the winter, producing a very uneven surface, the high parts of which are subsequently colonized by algae. They suggest that the trapping of sediment by the algal mats increases the amount of relief until it is sufficiently elevated for halophytes to take root and to subsequently raise and enlarge the area even more. As the halophyte hummocks grow and coalesce, they would eventually be welded onto the salt marsh. This process may occur, but isolated _Salicornia virginica_ and _Triglochin maritimum_ plants were seen to be growing directly on the tidal flats, apparently unrelated to algal mat mounds. These pioneer halophytes appear to withstand wave and current activity for a period long enough after germination to become rooted, but many may not withstand the stronger wave activity in winter. Algal mats were observed around the larger hummocks, and these would indeed contribute to their elevation. In the winter, the mounds are eroded, mainly on the seaward side.

The formation of hummocks by _Triglochin_ was studied in the Dovey Estuary by Yapp _et al_. (1917), who found that one or more _Triglochin_ plants became established on the silt, and their rhizomes grew out and up, trapping sediments and thereby increasing the relief of the hummock. Moody (1978) commented on the capacity of _Triglochin maritimum_ on Fraser foreshore marshes for elevating the marsh surface.

The ecological/sedimentological interaction of plant establishment and the increased capacity to trap sediments, which raises the elevation of the area, are well documented in the literature, and correspond to my observations in Boundary Bay. The binding and trapping of sediments by algae has been documented by Ginsburg et al. (1958) and Gebelein (1969). Grass roots acting as baffles, promoting sediment accumulation, and stabilizing the area are described by Bernatowicz (1952), Molinier and Picard (1952), Ginsburg (1956), Ranwell (1964), Scoffin (1970) and Patriquin (1975). Sedimentation rates of up to 2 cm per year are observed in areas colonized by Carex lyngbei at Woodward Island, Fraser River Estuary (Envirocon, 1980).

Development of the Salt Marsh

Salt marsh development does not appear to be that of a time-controlled succession migrating over the area, but rather appears related to elevation relative to sea level. The development is similar to that of salt marshes in other regions of the Northern Hemisphere and follows the stages in salt marsh formation described by Chapman (1960) in which he states that:

1. algae and/or eelgrasses colonize the mud or sand flat;
2. as the ground becomes higher, subaerial plants such as Salicornia spp. or Puccinellia spp. colonize the area;
3. the elevation increases and new species appear, increasing the accretion rate and replacing the primary colonists by successively more complex communities.

In the present study, evidence of salt marsh vegetation is found deeper (and earlier) in cores 3 and 5; these areas may represent topographic lows (possibly former channels) which were preferentially colonized earlier than at other sites. The development of the salt marsh, as interpreted from palynological analyses of the cores, is summarized in Figure 20; pollen diagrams of the cores may be found in Figures 23 through 33.

The salt marsh at 64th Street is interpreted as having developed on marine sands, commencing about 345±75 yrs B.P. (Teledyne, 1-11, 764), a date on organic-rich sands containing abundant Salicornia pollen at 24 cm in core 6. The origin of the sand is uncertain. They could represent deltaic sands deposited by the Fraser River, with some marine influence; however, their shallowness and situation on the inactive delta front suggest that they may be solely due to marine intertidal deposition and derived from Point Roberts or the Fraser River. The waters from which the sediments were deposited contained pollen of the main species of the Coast forest, as described by Krajina (1969); associated with these, the presence of foraminifera, dinoflagellate cysts and fine black detritus (Hebda, 1977) suggests a marine environment. Low abundances of pollen in the deeper samples were observed; chenopod pollen may represent an earlier development of a salt marsh but were more likely derived from elsewhere and redeposited with the sands.

Algal mats, which cover the inner tidal flats seaward of the salt marsh (Figure 15), locally have elevated areas, contributing to the initial development of the salt marsh; however, Salicornia appears to be the dominant pioneer halophyte in the

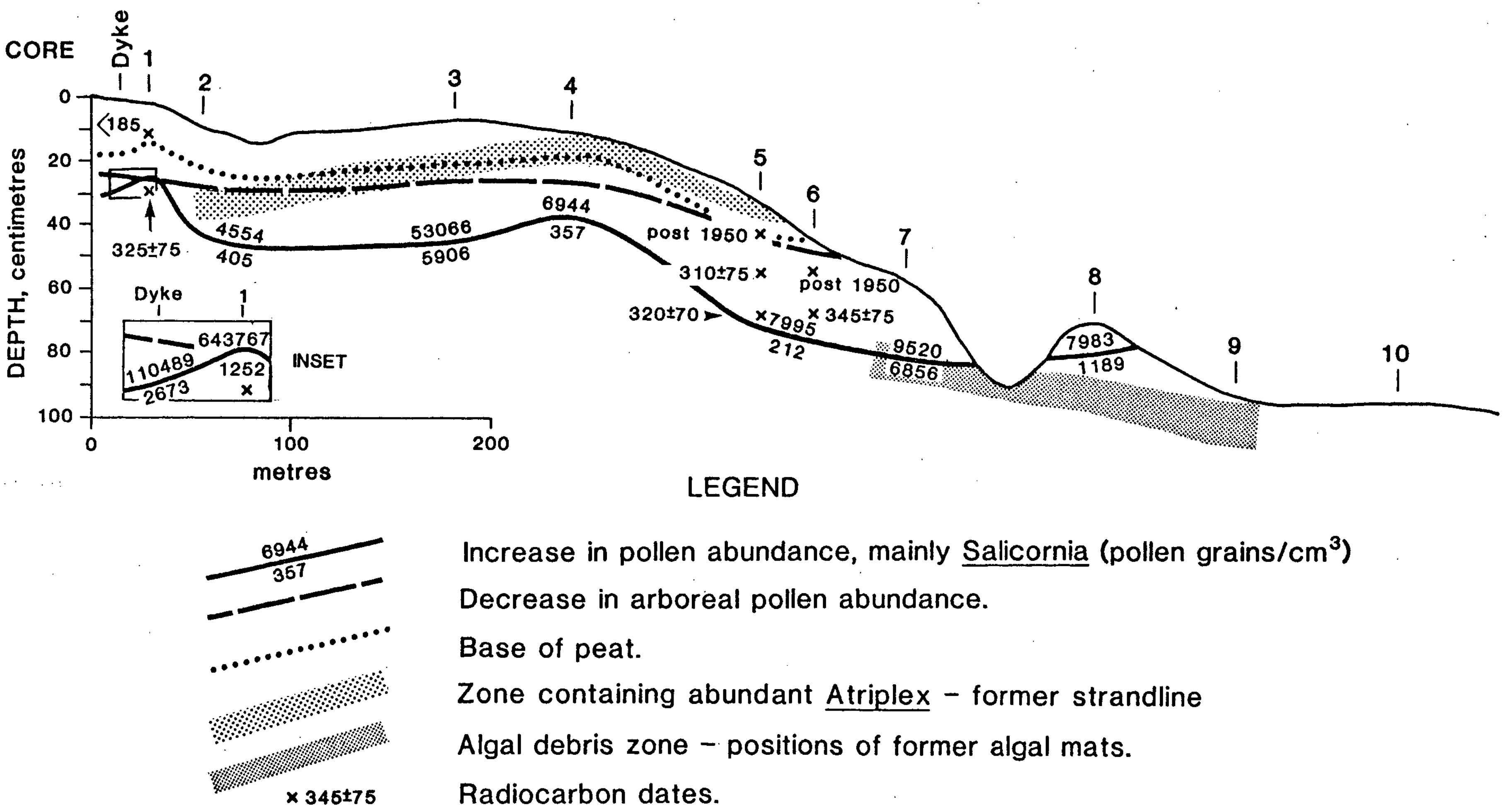
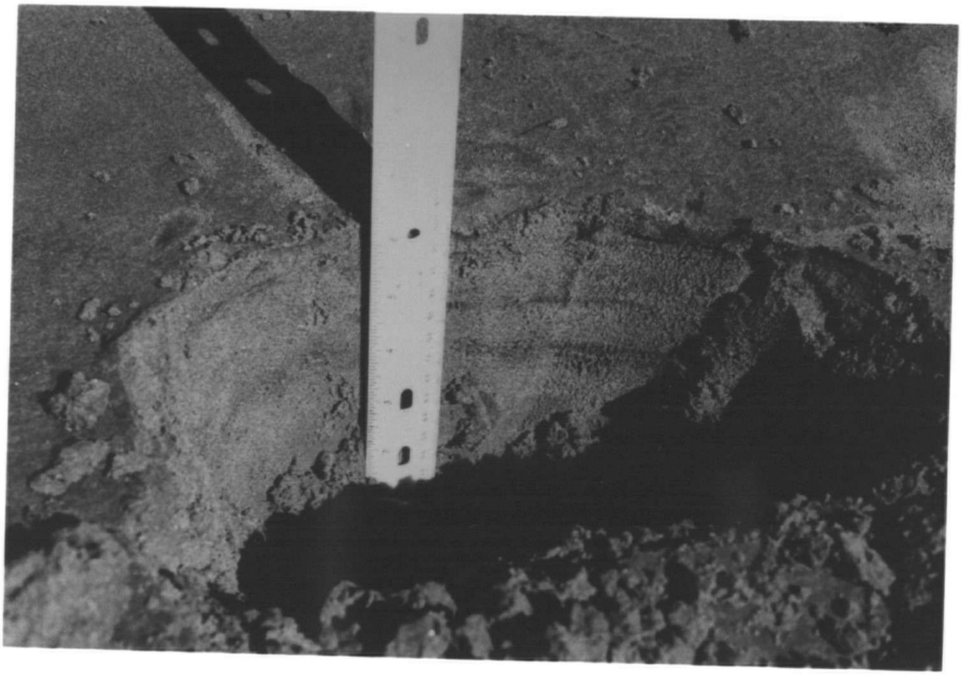


Figure 20. Summary of the development of the salt marsh at 64th Street.

cores, although associated with Triglochin in core 7. Salicornia can tolerate environments of higher salinities, but is reduced to a phylloclade form which has minute leaf appendages resistant to tearing by wave action, and has developed succulence, which makes it resistant to injury from salt (Ranwell; 1972). Colonization appears to be very rapid, pollen abundance suddenly increases with the appearance of Salicornia, suggesting that the area became stable or emergent. This is typical of many salt marshes; the threshold level for salt marsh plant growth develops quite suddenly, and new colonization over a large surface area may occur very rapidly (Ranwell, 1972). West (1956), for example, found that colonization of mud flats by mangroves in Colombia is quite sudden. As the salt marsh develops and becomes more emergent, marine inundations decrease in frequency; this can be seen in the cores by a decrease in abundance of coast forest pollen and a corresponding increase in halophytes and mesophytes.

Successive changes seen vertically in the cores can be related to the lateral vegetational sequence present on the modern tidal flats. The algal mat zone is colonized by Salicornia and Triglochin , as seen in cores 9 and 10. Algal debris in core 7 at 25-30 cm, in core 8 at 15-25 cm, and in core 9 represents positions of former algal mats. Laminated sediments were seen near station 8 (Figure 21), but these laminae were destroyed by vegetation roots and could not be traced landwards beneath the salt marsh. Salicornia and Triglochin became established as can be seen in core 8, and the formation of hummocks is apparent. At core 7, Spergularia and Cuscuta, which are also halophytes,

Figure 21. Algal laminations seen near Station 8.



are present. The vegetation becomes more diverse upwards; *Plantago* is found in core 6. A zone of *Atriplex*, marked at 0-5 cm in core 5, represents the strandline, and higher concentrations of *Atriplex* in the cores, such as at 0-10 cm in core 4 and 10-20 cm in core 3, may represent former positions of the strandline.

Seaward of station 5 is the lower, submergent marsh, which is frequently flooded; the abundance of coast forest pollen present in cores 6 through 10 reflects the marine character of this area.

Landward of station 5 is the upper, emergent marsh, upon which a peat is present. Successive changes in the pollen assemblages in the cores represent the emergence of a diverse mesophytic vegetation. *Grindelia* is a composite appearing lower in the cores, and is found out to station 6. A zone with abundant grasses then develops, and more composites are found higher in the cores as the vegetation becomes more established and varied. The most emergent zone is seen only at the inner margin of the marsh, in the dyke core and core 1, where *Aster*, *Agoseris*, and Rosaceae (probably *Malus fusca*) are found. *Salicornia* is present throughout the cores - it can live in many environments, whereas mesophytes are more highly specialized and require specific growth conditions. A widespread decrease in the proportions of coast forest species seen in the dyke core and cores 1, 2, 3, and 4 at about 20 cm suggests:

1) marsh emergence and marine floodings, accompanied by coast forest pollen, becoming less frequent;

2) coast forest pollen source-areas being removed; or

3) drainage channels flowing into the area being diverted away from a source of coast forest pollen (G.E. Rouse, 1980, oral commun.)

An increase in the abundance of Alnus near the top of most cores can be attributed to historical land clearing; Alnus is a pioneer species on disturbed sites. Dispersal of pollen by wind and water is apparent in the cores; species present in low abundances in the sands are thought to have been introduced.

Rates of Development and Accretion of the Salt Marsh

The salt marsh appears to have developed rapidly over a distance of 315 m from the dyke to station 5. A well developed, woody peat is found above the organic sandy clay and fine sands; the base of the organic rich sand, with an associated increase in pollen abundance, is taken as the commencement of salt marsh development, and has been dated as 320±70 years B.P. (GSC-3186) at a depth of 35 cm in core 5. There appears to have been a subsequent halt in the progradation of the marsh, and a small marine transgression is envisaged, as eelgrass and tidal debris overlies a woody peat in core 5. The seaward front of the marsh is presently developing over the tidal flats, as seen by palynological evidence in the cores.

The average rate of vertical accretion is 0.5 mm/yr at station 1, which is slow compared to 3 cm per year at station 5; this is due to deposition of organic debris by the tides at the latter site. The peat at station 1 may once have been thicker, with its upper part being destroyed by fire. Mineral charcoal, attributed to fire, was seen at 5 to 10 cm in the dyke core.

Algal laminae, seen between stations 7 and 8 (Figure 21), indicate 1 cm of sand being deposited annually for three years. Much erosion and reworking of the sediments occurs on the tidal flats, and this value is not representative of the overall sedimentation rate as interpreted from the radiocarbon dates.

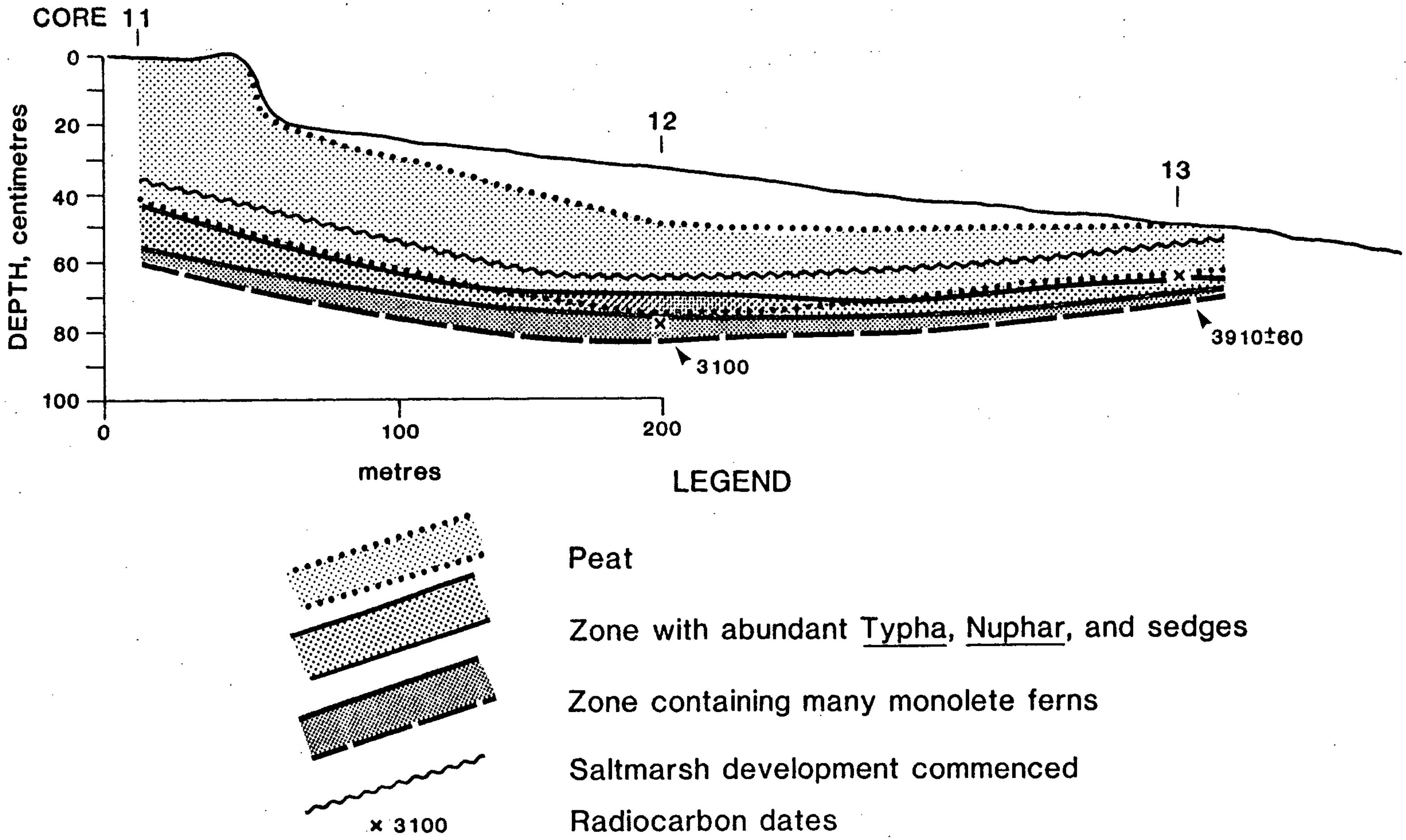
The Peat at 112th Street

A partly buried peat was studied on the foreshore south of 112th Street, South Delta, B.C. Where exposed, it is being actively eroded, but parts have been covered by silts and clays. Erosion was observed to be occurring in the east part of the Bay by Kellerhals and Murray (1969), who found that a cliff 60 cm high formed the seaward edge of the salt marsh at Mud Bay. The modern development of salt marsh vegetation occurs in a narrow discontinuous band immediately seaward of the dyke. Kellerhals and Murray (1969) described the buried peat as the remnant of a former extensive salt marsh. Wood embedded in the peat gave a radiocarbon age of 4350±100 years B.P. (GX-0781). They suggested that the marsh developed when the South Arm of the Fraser River flowed southward into Boundary Bay; subsidence later allowed the sea to transgress over and erode the earlier marsh deposit. The present study suggests a more complex history.

Three cores, 11, 12, and 13, (Figure 5) were collected and, from the pollen analyses (Figures 22, 34, 35 and 36), a paleoenvironmental reconstruction is suggested in which a freshwater pond or bog environment, perhaps associated with the "Great Channel" (Kellerhals and Murray, 1969), was successively inundated by marine waters and converted to a salt marsh. The succession was:

1. establishment of ferns, suggesting a freshwater environment;
2. *Typha*, *Nuphar*, and sedges grew in and around the freshwater area;

Figure 22. Composite section of zones found in the cores obtained near 112th Street.



3. gradual encroachment of seawater, the sedges being the most tolerant to the change in environment; and
4. the development of saltmarsh as indicated by Salicornia, Atriplex, and Triglochin.

Later, composites appeared as the marsh became more emergent. Grasses are abundant throughout the cores; Salicornia and Atriplex, present lower in the cores, may have been introduced or may represent vegetation growing on the ditch turf line around the freshwater bog (Chapman, 1976). Coast forest species (Krajina, 1969) are abundant in the freshwater environment; either a forest grew nearby or rivers transported these pollen into the area. The frequency of these pollen decreases with the advent of the salt marsh, as observed at 64th Street, but increases in core 12 at a depth of 16 cm, where marine waters deposited silts laden with such pollen above the peat. Core 11 shows the most emergent succession, whereas core 13 shows the commencement of salt marsh development; this can be explained by greater erosion of the peats further away from land by a transgressing sea.

The sequence seen in the peats at 112th Street is the reverse to that observed in New England salt marshes by Chapman (1960). He observed development from marine mud to eelgrass, to grasses, to sedges, and finally to a Typha reed swamp as the water becomes increasingly fresh. This cycle is associated with emergence; the sequence seen in the peats at 112th Street suggests submergence of a freshwater environment and subsequent emergence of the salt marsh. The sequence of events here corresponds to the that described by Kellerhals and Murray (1969).

They suggested that a freshwater environment prevailed where the South Arm of the Fraser River entered Boundary Bay; this environment was later covered with salt water, causing the vegetation to change and halophytes to increase in abundance.

CHAPTER 4: DISCUSSION AND CONCLUSIONS

The salt marsh at 64th Street appears to be a typical maritime salt marsh. A distinctive zonation of vegetation related to elevation was observed, with a varied mesophytic flora near the dyke. The vegetation becomes less diverse seaward and increasingly dominated by halophytes until _Salicornia_ and _Triglochin_ occur alone.

The development of the salt marsh, interpreted from palynological analyses of cores obtained in a transect across the study area (Figure 20), reflects the sequence observed horizontally at present (Figure 4). _Salicornia_ and occasional _Triglochin_ are the pioneer halophytes colonizing the sediments. Algal mat development may initially have contributed to an increase in elevation. As elevation is further increased, a corresponding increase in the abundance and diversity of pollen occurs. Associated with this, a marked reduction in the amount of arboreal pollen, transported by the sea water, signifies submergences becoming less frequent and the marsh emerging. A distinctive zone of _Atriplex_ represents former positions of the strandline. Further emergence occurred and continued until the marsh was sufficiently elevated for mesophytes to dominate the vegetation; peat accumulated and, in the most emergent zones, a varied, diverse flora persisted. Elevation is the dominant factor in the development of the marsh; as the marsh develops, a more varied vegetation enhances the increase in elevation.

Radiocarbon dates on organic-rich sands containing abundant _Salicornia_ suggest that the salt marsh commenced development about 345±75 yrs B.P. (Teledyne, 1-11, 764). Development is envisaged to have occurred in two stages; in the area between the dyke and Station 5, the area became emergent, and a peat developed beneath an increasingly diverse flora. A subsequent pause in development or a transgression occurred, during which eelgrass was deposited above the peat at station 5; this now forms the strandline. Following this, development of the marsh continued to the present.

The peat from 112th Street shows a succession from a freshwater to a salt marsh environment (Figure 22). Ferns grew and, later, Typha, Nuphar, and sedges developed. These decrease in abundance as the area is successively inundated by marine water, the sedges being the species most tolerant of the changing environment. Chenopod pollen becomes abundant as the salt marsh develops, and a trend towards emergence occurs as the vegetation becomes increasingly more diverse. The most complete sequence was observed in core 11.

Radiocarbon dates were obtained from the base of the peat; core 12 at 41 to 44 cm was dated as 3130±50 yrs B.P. (GSC-3202) and core 13 at 12 to 14 cm was dated as 3910±60 yrs B.P. (GSC-3183). From the same area, Kellerhals and Murray (1969) describe a peat dated at 4350±100 years B.P. (GX-0781), and Clague (written commun., 1980) obtained a date of 3780±90 yrs B.P. (GSC-3087) at a depth of 1 m in a peat immediately seaward of the dyke. These peats may represent one sequence from a freshwater to a salt marsh environment, or they could have developed in former channels, being subjected to periodic erosion and repeated salt marsh development.

Pollens and spores, being morphologically diverse and resistant to degradation, are valuable for the interpretation of paleoenvironments. The pollen of the salt marsh vegetation was observed to occur mainly in the source areas (Figure 17), and was not subject to widespread dispersal by wind and water as were the coast forest pollen. This was especially noticeable in the case of Salicornia pollen, which appear to be most widespread in a salt marsh environment.

This study has shown that palynologic analyses can be used to reconstruct stages in the development of salt marshes at Boundary Bay; similar studies may be equally successful in other areas. Palynoassemblage sequences can be used to identify the main transgressive and regressive phases of sedimentation in coastal environments, as seen here in the recognition of a freshwater to marine transition in the peat sequence at 112th Street.

REFERENCES CITED

Armstrong, J.E., 1956a, Mankato Drift in the Lower Fraser Valley of British Columbia, Canada: Geological Soc. America Bull., 67, 1666-1667.

Armstrong, J.E., 1956b, Surficial geology of Vancouver area, B.C.: Geological Survey of Canada Paper 55-40, 16 p. and map.

Armstrong, J.E., 1957, Surficial geology of New Westminster map-area, British Columbia: Geological Survey of Canada Paper 57-5, 25 p. and map.

Armstrong, J.E., 1960, Surficial geology of Sumas map-area, B.C.: Geological Survey of Canada Paper 59-9, 27 p. and map.

Armstrong, J.E., 1977, Quaternary stratigraphy of Fraser Lowland: Joint Annual Meeting of the Geological Association of Canada and the Mineralogical Association of Canada, Vancouver, British Columbia. Field Trip No. 10, Guidebook, 1-20.

Armstrong, J.E., 1979, Surficial geology, Vancouver, British Columbia: Geological Survey of Canada Map 1486A.

Armstrong, J.E., 1980, Surficial geology, Mission, British Columbia: Geological Survey of Canada Map 1485A.

Armstrong, J.E., and J.J. Clague, 1977, Two major Wisconsin lithostratigraphic units in southwest British Columbia: Can. Jour. Earth Sci., 14, 1471-1480.

Becker, R.E., 1971, An ecological perspective of the Fraser River Delta foreshore: The University of British Columbia, Department of Plant Science, M.Sc. essay, 49 p.

Bernatowicz, A.J., 1952, Marine monocotyledonous plants of Bermuda: Bull. Mar. Sci. Gulf and Carib., 2, 338-345.

Blunden, R.H., 1973, Urban geology of Richmond, British Columbia: Adventures in Earth Science Series No. 15, Department of Geological Sciences, The University of British Columbia, 13 p.

Blunden, R.H., 1975, Historical geology of the Lower Fraser River Valley: Adventures in Earth Science Series No. 3, Department of Geological Sciences, The University of British Columbia, 36 p.

British Columbia Department of Agriculture, 1971, Climate of British Columbia. Climatic normals, 1941-1970. British Columbia Department of Agriculture, 90 p.

Chapman, V.J., 1960, Salt marshes and salt deserts of the world: Leonard Hill, London, 392 p.

Chapman, V.J., 1976, Coastal vegetation (2nd ed.): Pergamon

Press Ltd., 292 p.

Clague, J.J., 1976, Quadra Sand and its relation to the late Wisconsin glaciation of southwest British Columbia: Can. Jour. Earth Sci., 13, 803-815.

Clague, J.J., 1978, Mid-Wisconsinian climates of the Pacific Northwest: In Current Research, Part B; Geological Survey of Canada Paper 78-1B, 95-100.

Clague, J.J., J.E. Armstrong, and W.H. Mathews, 1980, Advance of the Late Wisconsin Cordillera ice sheet in southern British Columbia since 22,000 B.P.: Quaternary Research, 13, 322-326.

Crickmay, C.H., and S.A.J. Pocock, 1963, Cretaceous of Vancouver, British Columbia, Canada: Am. Assoc. Petroleum Geologists Bull., 47, 1928-1942.

Envirocon, 1980, Fraser River Estuary habitat development program, Criteria Summary Report: prepared for Department of Supply and Services, Fisheries and Oceans, Canadian Wildlife Service, and Public Works Canada by Envirocon Ltd., Vancouver, British Columbia.

Forbes, R.D., 1972, A floral description of the Fraser River Estuary and Boundary and Mud Bays, British Columbia: prepared for the Fish and Wildlife Branch, B.C. Department of Recreation and Conservation, 94 p.

Fyles, J.G., 1963, Surficial geology of Horne Lake and Parksville map-areas, Vancouver Island, British Columbia: Geological Survey of Canada Memoir 318, 142 p. and map.

Garrison, R.E., J.L. Luternauer, E.V. Grill, R.D. MacDonald, and J.W. Murray, 1969, Early diagenetic cementation of recent sands, Fraser River Delta, British Columbia: Sedimentology, 12, 27-46.

Gebelein, C.D., 1969, Distribution, morphology, and accretion rate of recent subtidal algal stromatolites, Bermuda: Jour. Sedimentary Petrology, 39, 49-69.

Ginsburg, R.N., 1956, Environmental relationships of grain size and constituent particles in some South Florida carbonate sediments: Am. Assoc. Petroleum Geologists Bull., 40, 2384-2427.

Ginsburg, R.N., and H.A. Lowenstam, 1958, The influence of marine bottom communities on the depositional environment of sediments: Jour. Geology, 66, 310-318.

Hebda, R.J., 1977, The paleoecology of a raised bog and associated deltaic sediments of the Fraser River Delta, British Columbia: The University of British Columbia, Department of Botany, Ph.D. thesis, 202 p.

Hitchcock, C.L., and A. Cronquist, 1973, Flora of the Pacific

Northwest: An Illustrated Manual: University of Washington Press, Seattle, 730 p.

Hoos, L.M., and G.A. Packman, 1974, The Fraser River Estuary - status of environmental knowledge to 1974: Canada Department of the Environment, Regional Board, Pacific Region, Special Estuary Series No. 1, Vancouver, 516 p.

Hopkins, W.S., 1966, Palynology of Tertiary rocks of the Whatcom Basin, southwestern British Columbia and northwestern Washington: The University of British Columbia, Department of Geology, Ph.D. thesis, 184 p.

Hopkins, W.S., 1969, Palynology of the Eocene Kitsilano Formation, southwestern British Columbia: Can. Jour. Botany, 47, 1101-1131.

Johnston, W.A., 1921a, Sedimentation of the Fraser River Delta: Geological Survey of Canada Memoir 125, 46 p.

Johnston, W.A., 1921b, The age of the Recent Delta of the Fraser River, British Columbia, Canada: Am. Jour. Sci., 5th Series, 1, 447-453.

Johnston, W.A., 1921c, Pleistocene oscillation of sea level in the Vancouver region, British Columbia: Trans. Royal Society of Canada, 3rd Series, 15, Sect. 4, 9-19.

Johnston, W.A., 1922, The character of stratification of the sediment in the Recent delta of the Fraser River, British Columbia, Canada: Jour. Geology, 30, 115-129.

Johnston, W.A., 1923, Geology of Fraser River Delta map-area: Geological Survey of Canada Memoir 135, 87 p.

Kellerhals, P., and J.W. Murray, 1969, Tidal flats at Boundary Bay, Fraser River Delta, British Columbia: Bull. Can. Petroleum Geologists, 17, 67-91.

Krajina, V.J., 1969, Ecology of forest trees in British Columbia. Ecology of western North America, 2 (1): The University of British Columbia, Department of Botany, 1-147.

Ladner, T.E., 1979, Above the Sand Heads. A vivid account of life on the delta of the Fraser River 1868-1900, 181 p.

LeBlond, P.H., 1979, An explanation of the logarithmic spiral plan shape of headland-bay beaches: Jour. Sedimentary Petrology, 49, 1093-1100.

Luternauer, J.L., 1974, Geology of the Fraser River Estuary: In Hoos, L.M., and G.A. Packman, eds., The Fraser River Estuary - Status of Environmental Knowledge to 1974: Canada Department of the Environment Regional Board, Pacific Region, Special Estuary Series No. 1, Vancouver, 10-29.

Luternauer, J.L., and J.W. Murray, 1973, Sedimentation on the western delta-front of the Fraser River, British Columbia: Can. Jour. Earth Sci., 10, 1642-1663.

MacDonald, K.B., and M.G. Barbour, 1974, Beach and salt marsh vegetation of the North American Pacific Coast: p. 175-234 in Reinold, R.J., and W.H. Queen (eds.), 1974, Ecology of halophytes: Academic Press, New York.

Mathews, W.H., 1972, Geology of Vancouver Area of British Columbia: 24th International Geological Congress (Montreal), Field Excursion No. A05-C05, 47 p.

Mathews, W.H., J.G. Fyles, and H.W. Nasmith, 1970, Postglacial crustal movements in southwestern British Columbia and adjacent Washington State: Can. Jour. Earth Sci., 7, 690-702.

Mathews, W.H., and F.P. Shepard, 1962, Sedimentation of Fraser River Delta, British Columbia: Am. Assoc. Petroleum Geologists Bull., 46, 1416-1443.

Milliman, J.D., 1980, Sedimentation in the Fraser River and its estuary, southwestern British Columbia: Estuarine and Coastal Marine Science, 10, 609-633.

Molinier, R., and J. Picard, 1952, Recherches sur les herbiers de phanerogames marines du littoral Mediterranean francais: Ann. Inst. oceanographique, 27, 157-234.

Moody, A.I., 1973, Growth and distribution of the vegetation of a southern Fraser Delta marsh: The University of British Columbia, Department of Plant Science, unpubl. M.Sc. thesis, 153 p.

North, M.E.A., W.A. Dunn, and J.M. Teversham, 1979, Vegetation of southwestern Fraser Lowland, 1858-1880. lands Directorate, Environment Canada, Vancouver, B.C.

Parsons, C.O., 1975, Vegetation pattern in a salt marsh at Boundary Bay, British Columbia: Lambda, 1, 45-52.

Patriquin, D.G., 1975, "Migration" of blowouts in seagrass beds at Barbados and Carriacou, West Indies, and its ecological and geological implications: Aquatic Botany, 1, 163-189.

Pharo, C.H., and W.C. Barnes, 1976, Distribution of surficial sediments of the central and southern Strait of Georgia, British Columbia: Can. Jour. Earth Sci., 13, 684-696.

Ranwell, D.S., 1964, Spartina salt marshes in southern England: Jour. Ecology, 52, 79-105.

Ranwell, D.S., 1972, Ecology of salt marshes and sand dunes: Chapman and Hall, London, 258 p.

Rouse, G.E., W.H. Mathews, and R.H. Blunden, 1975, The Lions

Gate Member: a new Late Cretaceous sedimentary subdivision in the Vancouver area of British Columbia: Can. Jour. Earth Sci., 12, 464-471.

Rouse, G.E., 1977, Paleogene palynomorph ranges in western and northern Canada: p. 48-65 in Elsik, W.C., ed., Contributions of Stratigraphic Palynology, 1, Cenozoic palynology. Am. Assoc. Strat. Palynologists, Contri. Ser. 5A.

Scoffin, T.P., 1970, The trapping and binding of subtidal carbonate sediments by marine vegetation in Bimini Lagoon, Bahamas: Jour. Sedimentary Petrology, 40, 249-273.

Stockmarr, J., 1971, Tablets with spores used in absolute pollen anaysis: Pollen et Spores, 8, 615-621.

Swinbanks, D.D., 1979, Environmental factors controlling floral zonation and the distribution of burrowing and tube-dwelling organisms on Fraser Delta tidal flats, British Columbia: The University of British Columbia, Department of Geological Sciences and Institute of Oceanography, unpubl. Ph.D. thesis, 274 p.

Taylor G. deR., 1958, Delta's century of progress: Kerfoot-Holmes Printing Ltd., Cloverdale, 96 p.

Terris, E.M., 1973, Ladner: A pioneer study: Western Washington State College, Department of Geography, M.A. thesis, 172 p.

Weir, W., 1960, Boundary Bay reclamation: preliminary report, part III. Report on current measurements and tidal analysis: Private report of C.B.A. Engineering Ltd., Vancouver, B.C.

West, R.C., 1956, Mangrove swamps of the Pacific coast of Colombia: Ann. Assoc. Am. Geogr., 46, 98-121.

Yamanaka, K., 1975, Primary productivity of the Fraser Delta foreshore: yield estimates of emergent vegetation: The University of British Columbia, Department of Plant Science, M.Sc. thesis, 133 p.

Yapp, R.H., D. Johns, and O.T. Jones, 1917, The salt marshes of the Dovey Estuary: Jour. Ecology, 5, 65-103.

Yasso, W.E., 1965, Plan geometry of headland-bay beaches: Jour. Geology, 73, 702-713.

APPENDIX I

Pollen Diagrams and Descriptions of the Cores

Dyke Core (0-60 cm) (Figure 23)

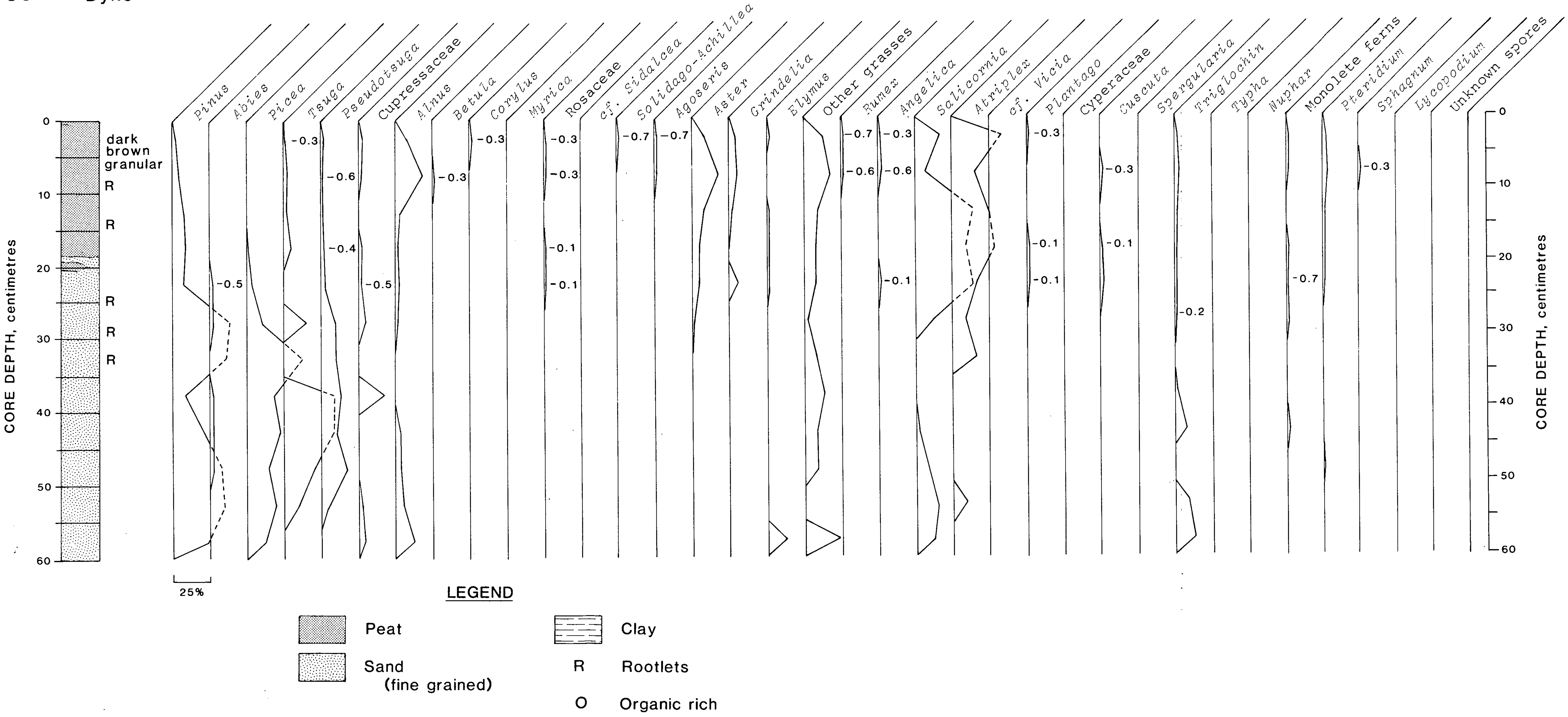
The most landward core was obtained 5.0 m south-southeast of the south side of the dyke at 64th Street (Figure 4). The sandy lower part of the core (30-60 cm) has a low palynomorph abundance. Dinoflagellate cysts occur at both 35-40 cm and 55-60 cm. Some Chenopod, Gramineae, and *Triglochin* pollen were found. Arboreal pollen is abundant in the lower part of the core, but shows a marked decline upwards as the salt marsh starts to develop at about 30 cm, accompanied by a sharp increase in the abundance of *Salicornia*. The pollen abundance increases from 2673 to 110,489 cm^{-3} as colonization and emergence occur. Peat persists from 20 cm upwards.

Above 15 cm, grasses, *Grindelia*, *Aster*, *Agoseris*, and Rosaceae are increasingly more abundant. There is a marked upward decrease in the proportion of coast forest pollen (Krajina, 1969) at about 20 cm, together with a corresponding increase in fungal spores.

Figure 23

TRANSECT LOCATION: 64th St., Boundary Bay

CORE Dyke



Core 1 (0-80 cm) (Figure 24)

In this core, sediments containing coast forest pollen and some dinoflagellate cysts are found up to a depth of 35 cm. At 30 cm, an abrupt increase in *Salicornia* occurs and the sands become slightly clayey and contain organic matter. *Triglochin* abundances increase also. Arboreal pollen abundance decreases upwards and peat formation begins at a depth of 14 cm. Grasses occur and the number of composites increase as the vegetational succession proceeds. The higher frequency of grasses lower in the core may be due to their being transported by water.

Core 2 (0-95 cm) (Figure 25)

In core 2, sands containing a low abundance of palynomorphs occur up to 35 to 40 cm. Higher frequencies of grasses, *Salicornia*, *Triglochin*, and *Atriplex* between 35-55 cm and 80-95 cm probably represent introduced pollen grains or short-lived, local patches of salt marsh vegetation. At 35 cm *Salicornia* and *Triglochin* increase. An increase in the abundance of grasses at 30 cm and the subsequent increases shown by *Grindelia* and *Aster* occur higher in the core. Peat has developed to a depth of 13 cm and coast forest pollens decrease in abundance higher in the core. A lack of Rosaceae here suggests that this area was not emergent enough for the growth of *Malus fusca*.

Figure 24

TRANSECT LOCATION: 64th St., Boundary Bay

CORE 1

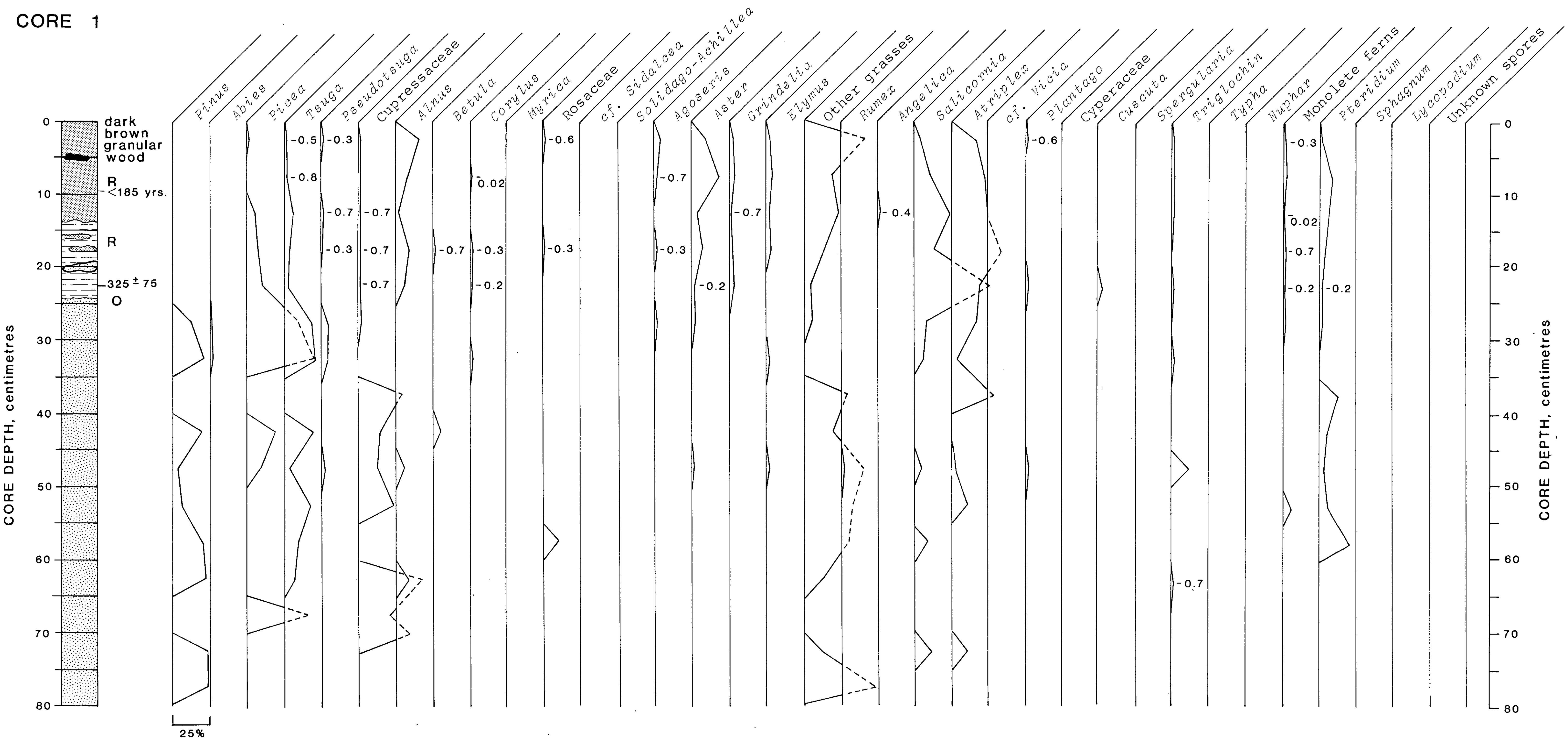
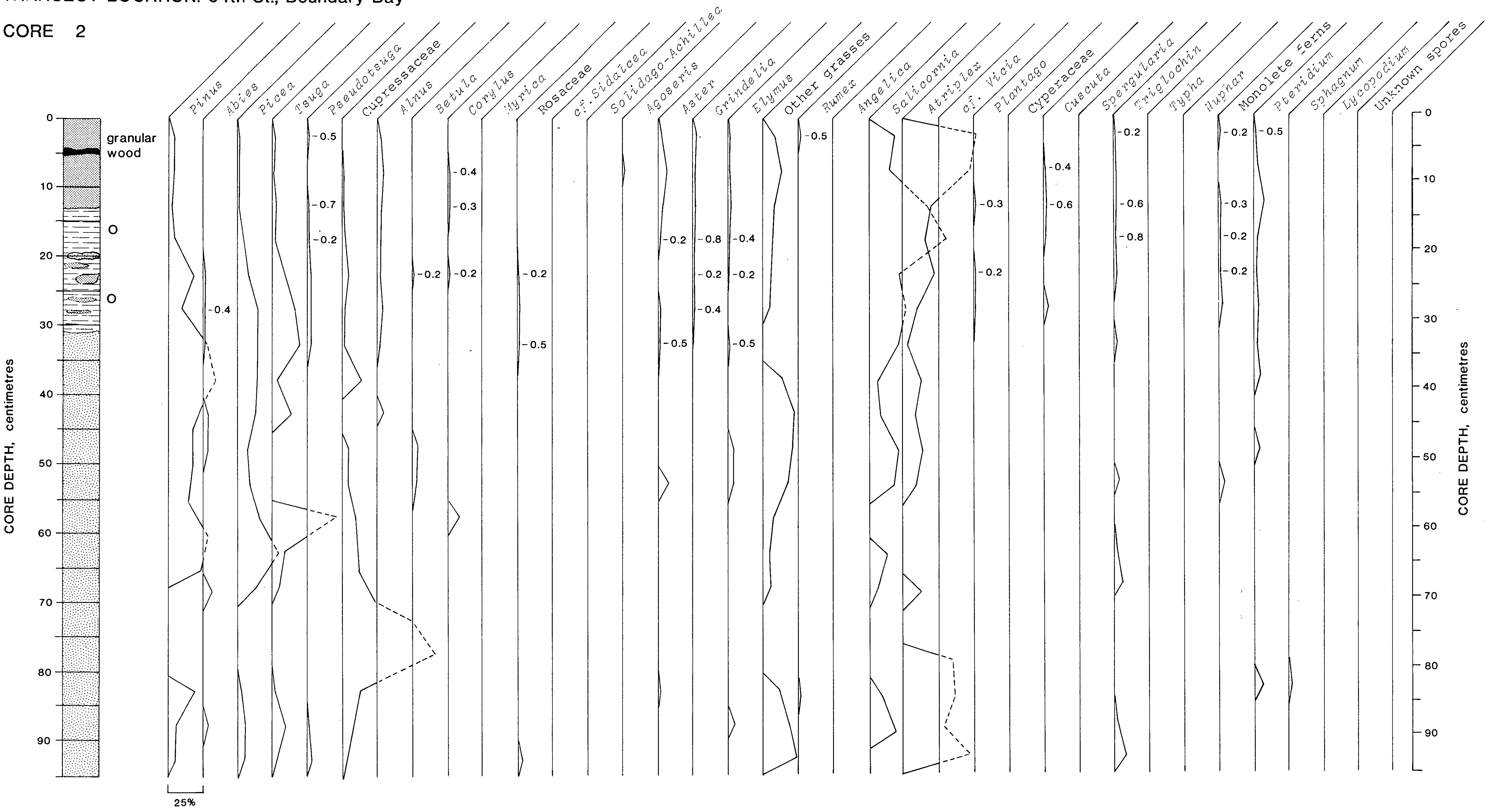


Figure 25

TRANSECT LOCATION: 64th St., Boundary Bay

CORE 2



Core 3 (0-60 cm) (Figure 26)

Sediments containing coast forest pollen occur up to 40 cm in core 3, with higher concentrations of *Salicornia*, *Atriplex*, and grasses probably being introduced into the sands. At 40 cm, arboreal pollen decreases and *Salicornia* increases dramatically. Successive increases in *Triglochin*, grasses, and *Atriplex* occur. Peat developed from 14 cm upwards, and *Aster*, *Grindelia*, and *Agoseris* are more abundant at the top of the core.

Core 4 (0-60 cm) (Figure 27)

In core 4, much algal debris was found in the sands up to a depth of 25 cm, where the pollen abundance increases from 357 to 6944 cm^{-3}, with *Salicornia* becoming abundant. *Salicornia*, *Atriplex*, and grasses are present in low abundances deeper in the core. Grasses, *Atriplex*, *Triglochin*, and *Cuscuta* (as a parasite on *Salicornia*) are present higher up, with *Grindelia* more abundant at the top. Coast forest pollen decreases dramatically at a depth of 15 cm.

Figure 26

TRANSECT LOCATION: 64th St., Boundary Bay

CORE 3

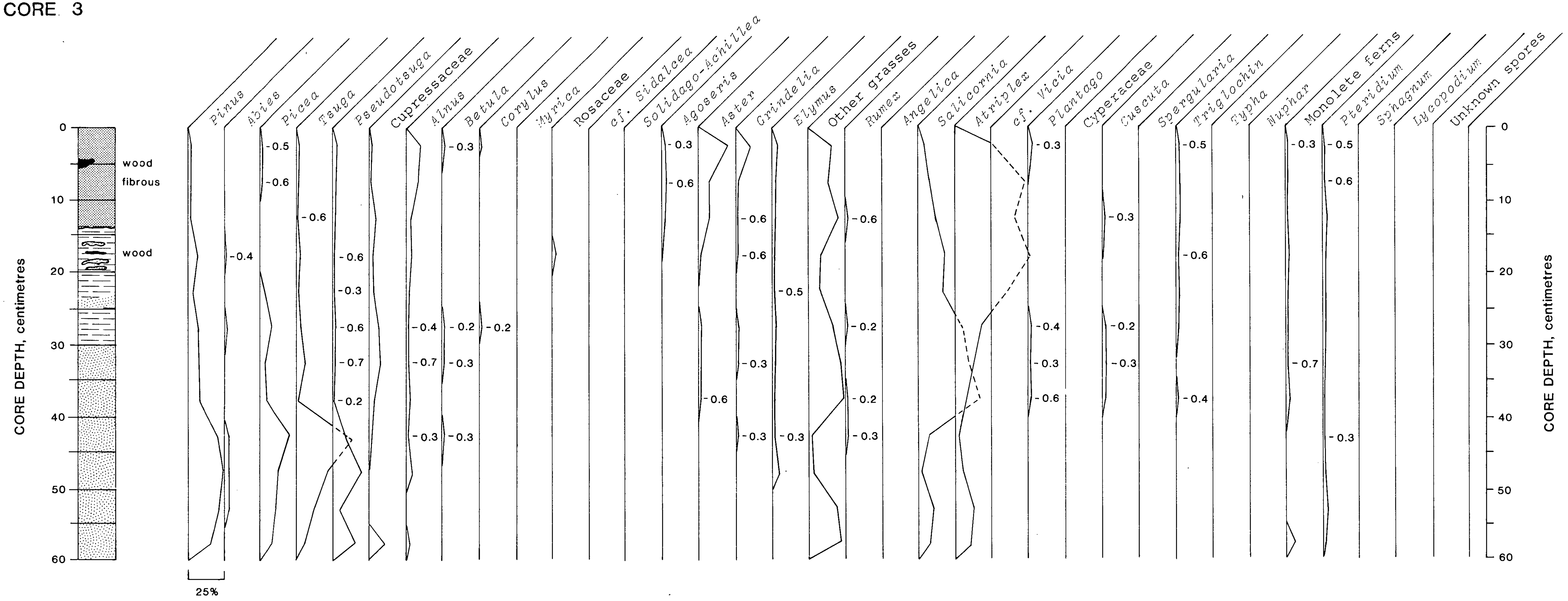
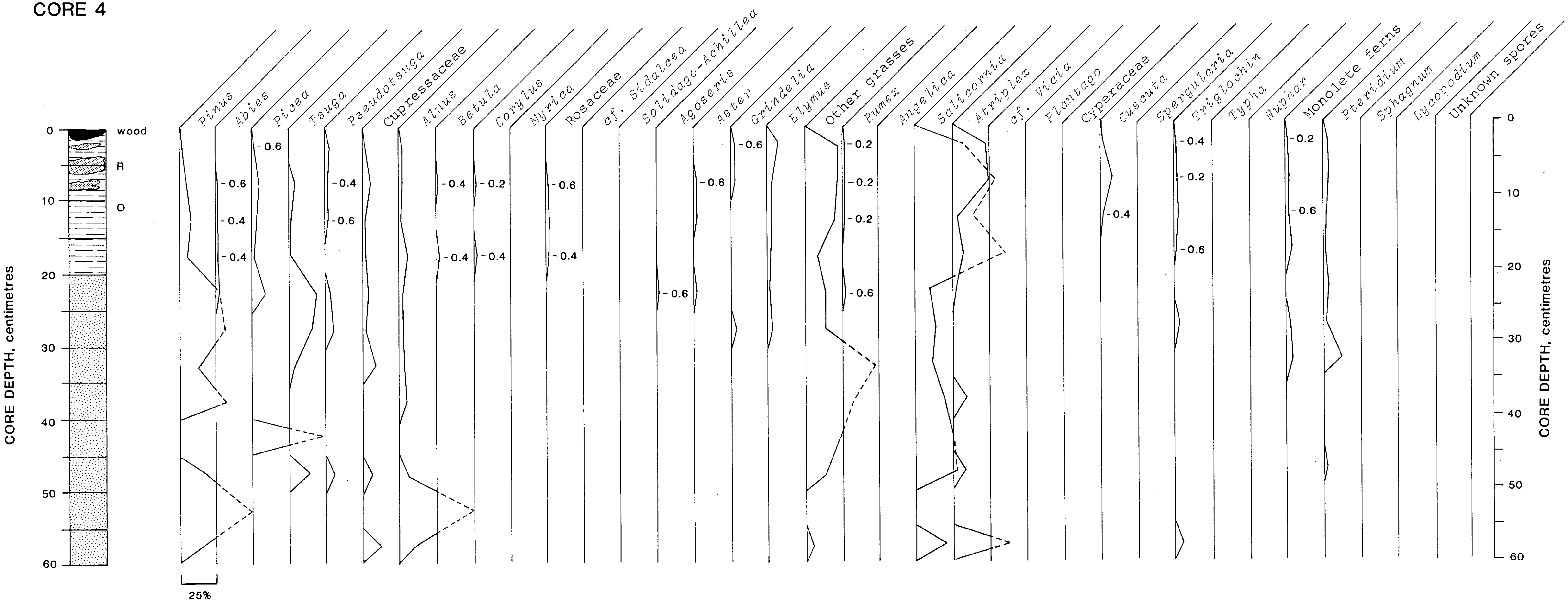


Figure 27

TRANSECT LOCATION: 64th St., Boundary Bay

CORE 4



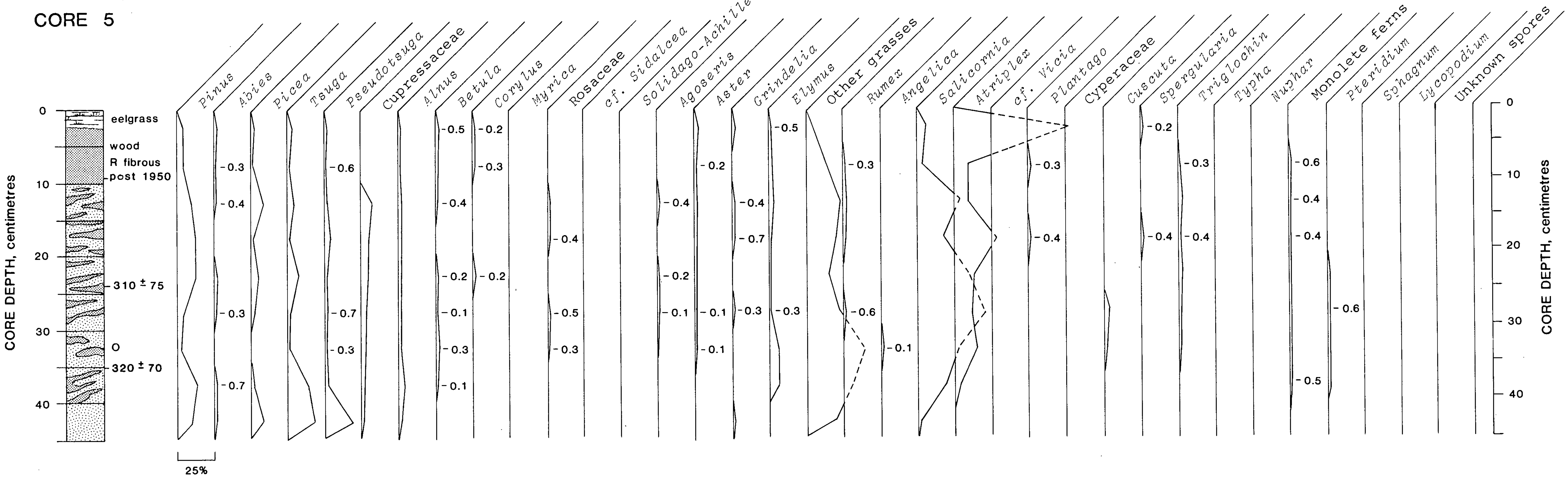
Core 5 (0-45 cm) (Figure 28)

The salt marsh appears to have commenced development deeper in core 5 than in any of the other cores. Between 40 and 45 cm, coast forest pollens are abundant. At 35-40 cm *Salicornia* and grasses increase, and a peaty horizon occurs. A subsequent decrease in grass abundance at 20-30 cm may signify that the environment, previously more emergent, became submergent or unsuitable for the continued growth of such grasses, leaving *Salicornia* as the dominant plant. This may represent colonization of a local high on the foreshore. Dinoflagellate cysts were found at 25-35 cm and 15-20 cm. *Salicornia* and *Triglochin* comprise the pioneer vegetation, with associated grasses and *Atriplex*, until *Atriplex* greatly increases in abundance at 0-5 cm and the others decline. The increase in *Atriplex* represents the colonization of the strandline, with a 4 cm thick eelgrass mat overlying the peat. *Grindelia* and *Aster* also occur higher in the core. Arboreal pollen decreases upwards, but occurs in higher frequencies at the top than in core 4; this suggests pollen deposited by higher winter tides and storms.

Figure 28

TRANSECT LOCATION: 64th St., Boundary Bay

CORE 5



Core 6 (0-30 cm) (Figure 29)

Core 6 is in the lower, submergent marsh. Salt marsh vegetation is present throughout the entire shallow core, but the presence of foraminifera indicates frequent submergence by marine waters. *Salicornia* is very abundant in the core, decreasing in frequency at 0-5 cm and apparently replaced by *Triglochin*, which shows a corresponding increase in frequency. Grasses are present throughout in significant numbers, with small amounts of *Atriplex* and *Plantago*. A lack of composites, with the exception of some *Grindelia*, is notable. The frequency of bladdered conifers decreases at 0-5 cm, associated with the formation of a peat and the commencement of emergence of the salt marsh.

Core 7 (0-30 cm) (Figure 30)

Salt marsh vegetation is present throughout the core but shows an increased abundance of *Triglochin* at 20-25 cm. *Salicornia* increases at 20 cm, whereas *Triglochin* decreases; this may indicate that the two species compete in the colonization of suitable areas. *Salicornia* and *Triglochin*, with grasses, and some *Atriplex* and *Plantago* higher in the core, make up the main vegetation here. Again, a lack of composites was observed, and foraminifera and some algal debris distributed throughout the core suggest frequent marine inundations. Coast forest pollens decrease at 0-5 cm.

Figure 29

TRANSECT LOCATION: 64th St., Boundary Bay

CORE 6

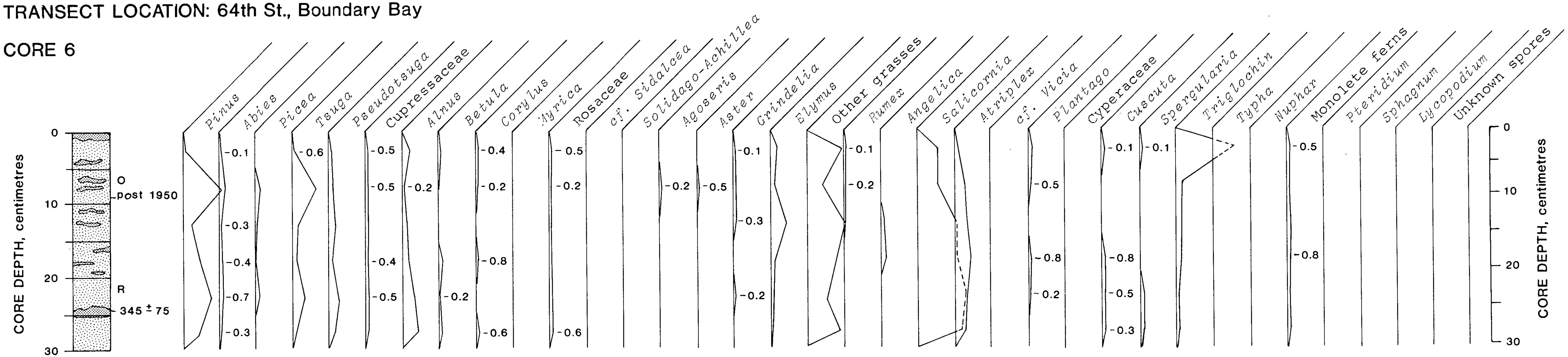
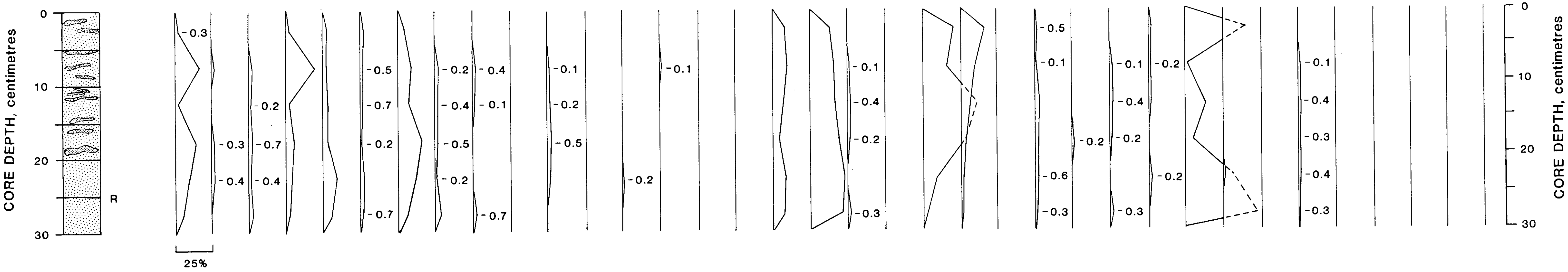


Figure 30 CORE 7



Core 8 (0-30 cm) (Figure 31)

Core 8, taken from a hummock at the seaward edge of the salt marsh, does not show the significant increase in *Salicornia* observed in other cores. *Salicornia*, *Triglochin*, grasses, and *Atriplex* are present throughout the core, with some *Plantago* at the top. The area is frequently flooded, and pollen of coast forest species are abundant throughout. Concentrations of algal debris at 15-25 cm may represent positions of formal algal mats, whilst a corresponding low in *Triglochin* may suggest local erosion and retreat of the strandline.

Core 9 (0-15 cm) (Figure 32)

This core, taken in the algal mat zone, contains algal debris and shows no development of salt marsh vegetation. Small amounts of *Salicornia*, *Triglochin*, *Atriplex*, and grasses are present throughout, with occasional *Plantago* and *Aster*; these probably were derived from the inner zone of the salt marsh. Coast forest pollen was introduced by seawater, and a sharp increase in *Alnus* occurs at 5 cm.

Core 10 (0-10 cm) (Figure 33)

Core 10, taken from the most seaward small *Triglochin* hummock, contains *Triglochin*, *Salicornia*, *Atriplex*, grasses, and arboreal pollen, all of which, with the exception of some *Triglochin*, have been derived from outside the zone where the core was taken. *Alnus* shows a high frequency in core 10, as it does in core 9.

Figure 31

TRANSECT LOCATION: 64th St., Boundary Bay

CORE 8

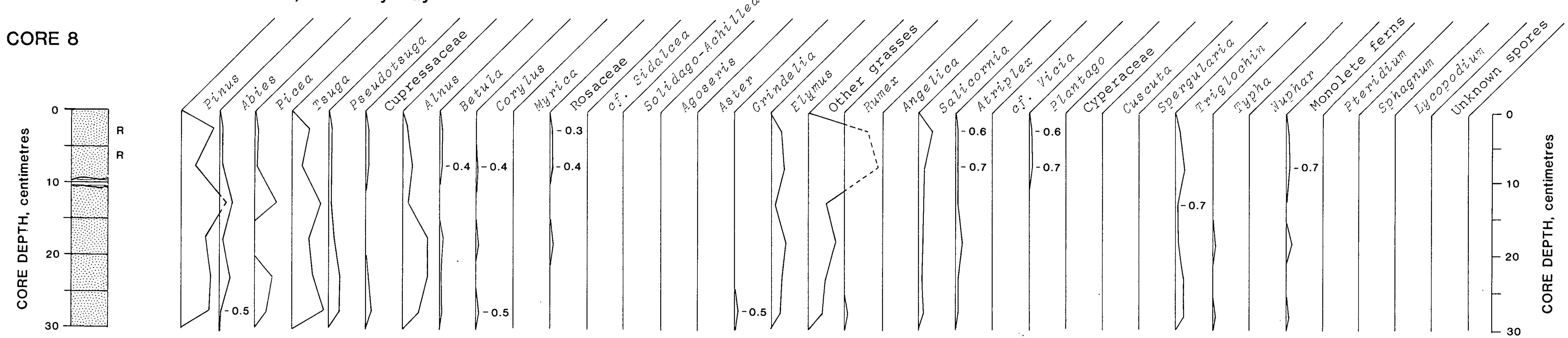


Figure 32 CORE 9

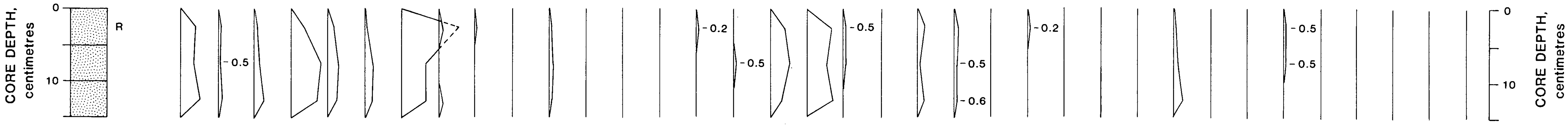
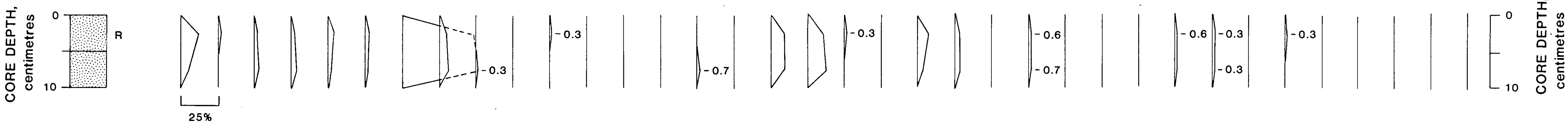


Figure 33 CORE 10



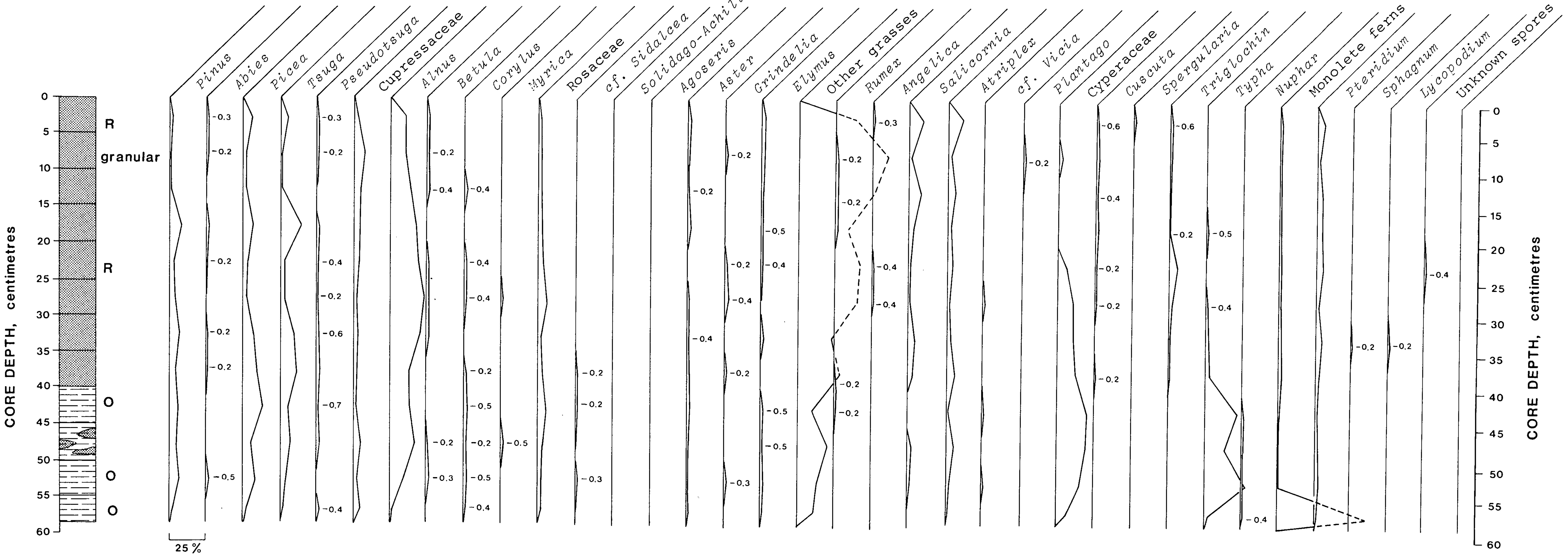
Core 11 (0-58 cm) (Figure 34)

Laevigato ferns dominate the organic-rich clays at 50-58 cm. *Typha* and sedges increase in abundance at 45-50 cm and remain the dominant vegetation up to 35-40 cm. Some *Nuphar* and *Pteridium* are associated with these plants also. Grasses occur and some coast forest species are present, perhaps introduced by marine waters or blown in from the nearby forested area of the Blaine Uplands (Figure 1). Higher frequencies of *Salicornia* and *Atriplex* occur sporadically. *Typha* and sedges decrease in abundance at about 40 cm, the base of the peat, suggesting the beginning of submergence of the area, with the freshwater vegetation gradually dying out. *Typha* can withstand salinities to 1.13% in the soil water (Penfold and Hathaway, 1938), and some sedges and rushes can live in brackish environments, as seen by the present occurrence of *Juncus* in the salt marsh at 64th Street. *Salicornia* and *Triglochin* increase at about 40 cm. *Atriplex* and grasses are present higher in the core and small numbers of *Aster* and *Grindelia* represent a diversifying vegetation. Coast forest pollen decreases at the top of the core.

Figure 34

TRANSECT LOCATION: 112th St., Boundary Bay

CORE 11



Core 12 (0-46 cm) (Figure 35)

Monolete ferns dominate the basal peaty clay at 41-46 cm in core 12, obtained 200 m seaward of the dyke, decreasing upwards in the peat at 41 cm, where Typha and sedges become numerous. Aster, Salicornia, and Atriplex are present in low frequencies in the peaty clay. Coast forest pollen is abundant up to 36 cm, and grasses are numerous. Salicornia, Triglochin, and Atriplex increase at 36 cm; Typha ceases at this depth and sedges become abundant. Upwards in the core, increasing amounts of halophytes and grasses occur; still higher, Grindelia and Aster are present. Salt marsh pollen cease at a depth of 16 cm. The overlying clays and silts contain black detritus, Foraminifera, coast forest pollen, and some introduced mesophyte and halophyte pollen.

Core 13 (0-18 cm) (Figure 36)

Core 13, obtained 300 m seaward of the dyke and immediately west of the "Great Channel", was found to contain ferns and Typha in the lower organic clays, associated with small amounts of Nuphar, sedges, and coast forest pollen. At 12 cm depth (the base of the peat), Typha, ferns, and coast forest vegetation sharply decline, whilst sedges, Pteridium, and grasses increase; this may represent the beginning of marine inundations of the area. Salicornia, Triglochin, and Atriplex increase in abundance at about 6 cm. Here, as in core 12, the upper emergent salt marsh peat is truncated; it may not have developed, but more likely it has been eroded away.

Figure 35

TRANSECT LOCATION: 112th St., Boundary Bay

CORE 12

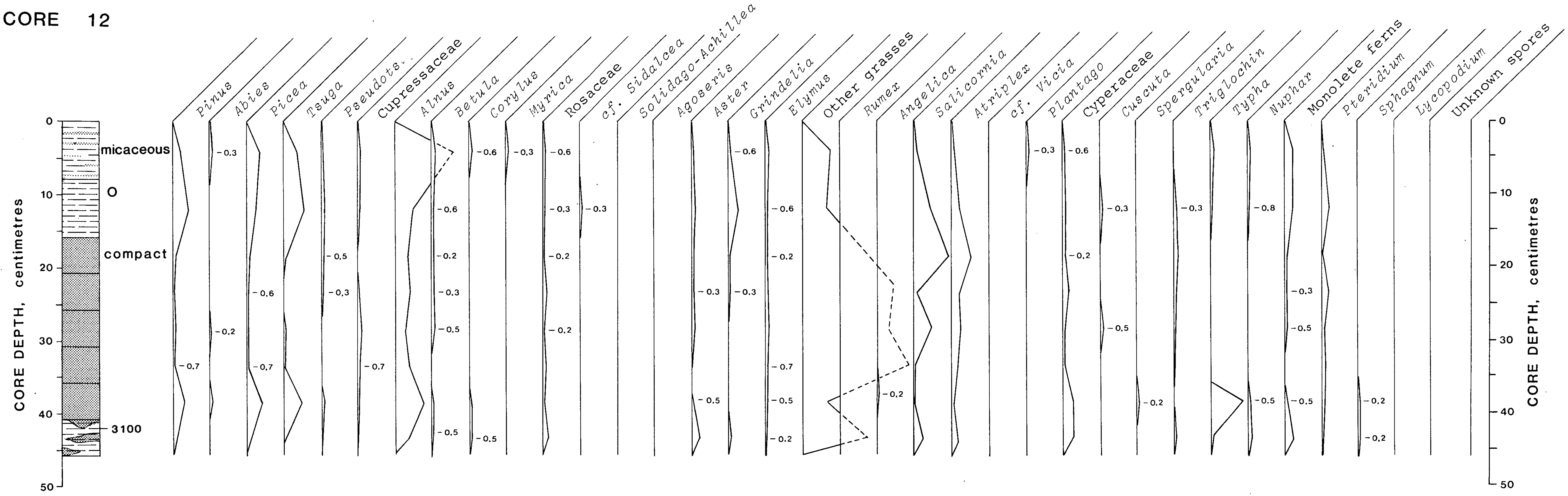
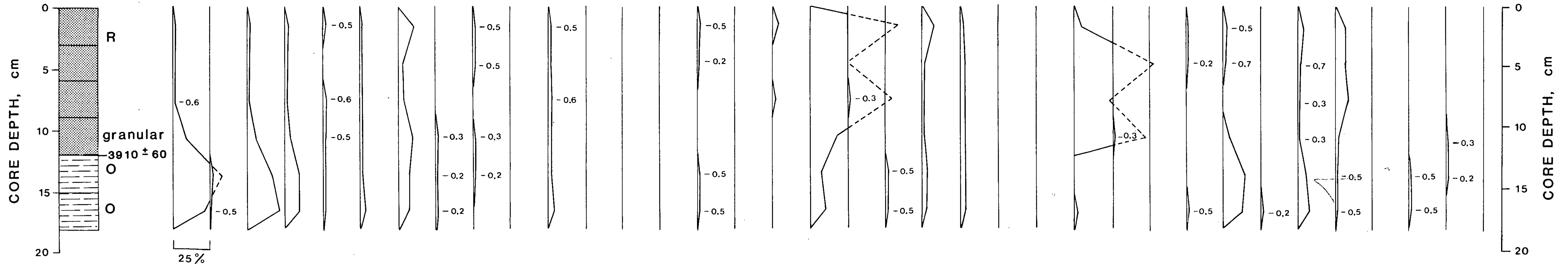


Figure 36 CORE 13



APPENDIX II

Pollen Assemblage Data for the Stations on the Salt Marsh at 64th Street

Pollen assemblage data for Station 1.

	May	June	July	Aug.	Sept.	Oct.	Nov.
Pinus		11	15	4	1		4
Abies	1						
Picea							
Tsuga		7	7	1	1		2
Pseudotsuga	4	2	3	2			
Cupressaceae		6					
Alnus	3	7	13	3	1	1	6
Betula		1					
Corylus	5						
Myrica							
Rosaceae		4	16	6	8	2	1
Sidalcea		2	61	20	1		
Solidago-Achillea			21	32	6		
Agoseris	1		611	679	163	3	17
Aster			19	90	36	137	47
Grindelia				17	5	1	3
Elymus	3	126	110	12	8	5	2
Other grasses		906	1886	41	329	12	230
Rumex	1	5	11	2			
Angelica		87	102	1			
Salicornia		4	22	22		1	
Atriplex		1	8	66	58	18	14
Vicia							
Plantago	2	10	5	2		1	
Juncus		62	2				
Cuscuta							
Spergularia							
Triglochin		35	100	4			
Typha			1	1			
Nuphar							
Monolete ferns				1	2		
Pteridium							1
Sphagnum							
Lycopodium							
Unknown spores							

Pollen assemblage data for Station 2.

	May	June	July	Aug.	Sept.	Oct.	Nov.
Pinus		21	11	8			
Abies							
Picea							
Tsuga		2	2	1	1		6
Pseudotsuga	3	1		3			
Cupressaceae							
Alnus		4	6	11	1		10
Betula		1		2			
Corylus							
Myrica							
Rosaceae		8	6			3	1
Sidalcea							
Solidago-Achillea		1	11	2			
Agoseris		1	43	16	3		1
Aster		1	137	306	428	39	201
Grindelia				41	26		5
Elymus	3	100	191	22	28		12
Other grasses		1247	577	126	30	9	79
Rumex		4	4	2			
Angelica		30	56				
Salicornia			7	44	7	2	2
Atriplex		5	17	280	147	6	53
Vicia							
Plantago		7	5	1	2		
Juncus		6	1				
Cuscuta							
Spergularia							
Triglochin		2	2				3
Typha			1				
Nuphar							
Monolete ferns					1		2
Pteridium							1
Sphagnum							
Lycopodium							
Unknown spores							

Pollen assemblage data for Station 2a.

	June	July	August	Sept.
Pinus	23	20	21	10
Abies	1		1	
Picea				
Tsuga	6	3	6	5
Pseudotsuga	1			
Cupressaceae				
Alnus	20	20	37	17
Betula		4	2	
Corylus				
Myrica				
Rosaceae				40
Sidalcea		1	1	
Solidago-Achillea	2	7		
Agoseris	1	4	3	2
Aster	2	8	89	246
Grindelia		4	39	295
Elymus	34	112	9	28
Other grasses	1081	1083	196	400
Rumex	4	4		
Angelica	5	28		
Salicornia	7	147	59	57
Atriplex	12	138	470	317
Vicia				
Plantago	16	21		
Juncus	3			
Cuscuta	1			
Spergularia				
Triglochin	7			
Typha				
Nuphar				
Monolete ferns	2	1		1
Pteridium				
Sphagnum				
Lycopodium				
Unknown spores				

Pollen assemblage data for Station 3.

	May	June	July	Aug.	Sept.	Oct.	Nov.
Pinus		12	29	2	4	1	2
Abies							
Picea							
Tsuga	2	5	3	1	1		
Pseudotsuga	3	1		4			
Cupressaceae	3						
Alnus		11	33		12		11
Betula		1	2				
Corylus		1					
Myrica							
Rosaceae		1	7	2	9		
Sidalcea							
Solidago-Achillea							
Agoseris	1		3	7	8		
Aster			3	366	359	6	22
Grindelia				36	148		1
Elymus	1	101	133	21	14		2
Other grasses	4	1002	969	118	69	5	17
Rumex			3				
Angelica		10	24				
Salicornia	1	1	67	236	77		
Atriplex	1	2	17	429	359	29	37
Vicia							
Plantago	1	10	5	1			
Juncus							
Cuscuta							
Spergularia							
Triglochin		3	4				
Typha			2				
Nuphar							
Monolete ferns							
Pteridium							
Sphagnum							
Lycopodium							
Unknown spores							

Pollen assemblage data for Station 3a.

	June	July	August	Sept.
Pinus	5	36	8	
Abies				
Picea				
Tsuga	7	3		
Pseudotsuga		6	1	1
Cupressaceae				
Alnus	13	27	6	
Betula				
Corylus				
Myrica				
Rosaceae	1	26	1	1
Sidalcea				
Solidago-Achillea				
Agoseris		81	57	
Aster		4	187	145
Grindelia			38	47
Elymus	124	151	14	1
Other grasses	521	982	131	31
Rumex	1	9	1	
Angelica	158	226	1	1
Salicornia	2	106	174	14
Atriplex	8	11	758	389
Vicia				
Plantago	11	18	4	1
Juncus				
Cuscuta				
Spergularia				
Triglochin	4			
Typha		9		
Nuphar				
Monolete ferns				1
Pteridium				
Sphagnum				
Lycopodium				
Unknown spores				

Pollen assemblage data for Station 4.

	May	June	July	Aug.	Sept.	Oct.	Nov.
Pinus	1	26	24	2	6	2	1
Abies		2	2				
Picea							
Tsuga	4	11	4			1	2
Pseudotsuga	4	2	1	2	1		1
Cupressaceae		1	1				
Alnus	3	63	30	3	1		
Betula	2	2	1		1	1	
Corylus	1	1					
Myrica							
Rosaceae		5	9	1	20	1	
Sidalcea							
Solidago-Achillea							
Agoseris			4	5			
Aster			2	15	4	8	31
Grindelia		5	5	87	291	10	8
Elymus		29	30	5	5		
Other grasses	7	252	360	17	15		10
Rumex		2	5				
Angelica		17	10				
Salicornia	9	70	252	322	74	15	17
Atriplex	21	329	349	957	904	300	210
Vicia							
Plantago	4	22	10				
Juncus							
Cuscuta							
Spergularia							
Triglochin		3	2	4	3		
Typha			1				
Nuphar							
Monolete ferns		1			2		
Pteridium							
Sphagnum							
Lycopodium							
Unknown spores							

Pollen assemblage data for Station 5.

	May	June	July	Aug.	Sept.	Oct.	Nov.
Pinus		23	12	1	1		9
Abies		2	2				
Picea							
Tsuga	3	12	2	2		2	5
Pseudotsuga	6		2	1			
Cupressaceae							2
Alnus		9	20				13
Betula			1				
Corylus							
Myrica							
Rosaceae		3	8	1			
Sidalcea							
Solidago-Achillea							
Agoseris							1
Aster			2	3	3		17
Grindelia			12	73	73	25	16
Elymus	2	66	80	1	10		1
Other grasses	2	342	992	20	6		14
Rumex		1	1				
Angelica		2	6				
Salicornia			72	94	23	12	18
Atriplex	2	8	178	1325	1071	400	237
Vicia							
Plantago		31	16				
Juncus							
Cuscuta							
Spergularia							
Triglochin	1	17	58	1	2		
Typha							
Nuphar							
Monolete ferns							
Pteridium							
Sphagnum							
Lycopodium							
Unknown spores							

Pollen assemblage data for Station 6.

	May	June	July	Aug.	Sept.	Oct.
Pinus		52	46	23	26	1
Abies		4	4			
Picea			2			
Tsuga		20	6	2	2	
Pseudotsuga	10	4	1	3	1	
Cupressaceae						
Alnus	1	33	16	3	9	2
Betula		3	3			
Corylus	3	1				
Myrica						
Rosaceae			4		2	2
Sidalcea						
Solidago-Achillea						
Agoseris			6	1	1	
Aster			1	8	37	
Grindelia			1	95	113	4
Elymus	6	23	32	7	12	
Other grasses	4	422	166	42	44	8
Rumex	1		1		—	
Angelica		3	3			
Salicornia		26	936	415	70	18
Atriplex	2	7	86	824	740	55
Vicia						
Plantago		543	218	6	12	
Juncus		6	3			
Cuscuta			4	1	6	
Spergularia				1	8	
Triglochin		151	121	18	6	
Typha						
Nuphar		—				
Monolete ferns		2	2		3	
Pteridium						
Sphagnum						
Lycopodium		1				
Unknown spores						

Pollen assemblage data for Station 7.

	May	June	July	Aug.	Sept.
Pinus		43	32	13	6
Abies		2	1		
Picea		4	3		
Tsuga	6	8	7	2	1
Pseudotsuga	10	8	1	1	1
Cupressaceae			2		
Alnus	5	23	13	1	3
Betula		2	2		1
Corylus		1			
Myrica					
Rosaceae			1	1	
Sidalcea			1		
Solidago-Achillea					
Agoseris			1	1	
Aster					1
Grindelia			1		
Elymus	1	35	38	13	4
Other grasses	19	150	90	58	39
Rumex		1	10		
Angelica			2		
Salicornia		8	814	665	305
Atriplex		5	34	354	284
Vicia					
Plantago		1080	355	7	4
Juncus					
Cuscuta			2		
Spergularia					
Triglochin		68	98	6	8
Typha			1		
Nuphar					
Monolete ferns		1			1
Pteridium					
Sphagnum					
Lycopodium					
Unknown spores					

Pollen assemblage data for Station 8.

	May	June	July	Aug.	Sept.
Pinus	18	185	101	24	74
Abies	3	12	2		1
Picea	1	18	7	2	3
Tsuga	24	49	32	8	28
Pseudotsuga	16	36	30	3	7
Cupressaceae	6	9	7	1	
Alnus	42	230	101	33	66
Betula	6	11	5	4	6
Corylus	2	5			
Myrica					
Rosaceae		1	2	1	1
Sidalcea					
Solidago-Achillea					
Agoseris		2	1		1
Aster		1	1	2	2
Grindelia			1	1	2
Elymus	4	29	30	21	27
Other grasses	12	24	56	41	45
Rumex		1	1		
Angelica					
Salicornia	6	24	46	113	32
Atriplex	6	16	11	66	33
Vicia					
Plantago	1	15	11	2	4
Juncus					
Cuscuta					
Spergularia				1	
Triglochin		34	29	25	6
Typha					
Nuphar					
Monolete ferns		4	4	1	18
Pteridium					
Sphagnum					
Lycopodium					
Unknown spores					1

Pollen assemblage data for Station 9.

	May	June	July	Aug.	Sept.
Pinus	26	168	69	53	35
Abies		4	3		4
Picea	2	23	5	2	3
Tsuga	36	60	61	27	7
Pseudotsuga	11	42	6	4	1
Cupressaceae	8	6	4		1
Alnus	101	120	84	56	36
Betula	6	9	10	4	2
Corylus				1	1
Myrica		2	1		
Rosaceae	3	1	2	4	
Sidalcea					
Solidago-Achillea					
Agoseris			1	5	
Aster					
Grindelia				2	
Elymus	8	38	25	32	13
Other grasses	44	53	42	33	42
Rumex			1		
Angelica					
Salicornia	16	14	28	75	10
Atriplex	1		7	140	33
Vicia					
Plantago	3		2	8	
Juncus					
Cuscuta			4	6	1
Spergularia					1
Triglochin	7	6	7	9	
Typha				3	1
Nuphar					
Monolete ferns		1	4	1	1
Pteridium					
Sphagnum					
Lycopodium	2		2		
Unknown spores					

Pollen assemblage data for Station 10.

	May	June	July	Aug.	Sept.
Pinus	14	330	133	80	21
Abies		10	1	4	1
Picea	1	33	13	6	1
Tsuga	21	156	89	42	9
Pseudotsuga	22	26	46	6	4
Cupressaceae	5	8	6	2	
Alnus	50	272	134	95	73
Betula	5	17	11	10	5
Corylus					
Myrica		1	1		
Rosaceae	2	2	7	4	4
Sidalcea			1		
Solidago-Achillea					
Agoseris					1
Aster				1	
Grindelia				1	
Elymus	12	71	89	40	17
Other grasses	25	126	104	34	22
Rumex			5	4	
Angelica					
Salicornia	14	45	67	37	6
Atriplex	1	1	3	98	33
Vicia					
Plantago	2	2	13	7	
Juncus					
Cuscuta			19	1	
Spergularia					
Triglochin	2	27	23	2	
Typha				1	
Nuphar					
Monolete ferns		4	5	5	1
Pteridium					
Sphagnum					
Lycopodium	2				
Unknown spores					