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PALEOECOLOGY OF POSTGLACIAL SEDIMENTS
IN THE FRASER LOWLAND REGION OF
BRITISH COLUMBIA

by

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THE UNIVERSITY OF BRITISH COLUMBIA

May, 1973

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ABSTRACT

The postglacial vegetation history of the University of British Columbia Research Forest and the Yale area in the Fraser Lowland region was investigated using percentage and absolute pollen analysis, macrofossil analysis, and radio-carbon dating. A marine clay deposit from the U.B.C. Forest records the oldest ($12,690 \pm 190$ B.P.) assemblage of terrestrial plant remains so far recovered from the postglacial of south-coastal British Columbia. Lodgepole pine dominated this early vegetation, although some fir, spruce, alder and herbs were also present. Four lakes were also studied paleoecologically. The oldest is Marion L., where a previously undescribed pollen assemblage of *Pinus contorta*, *Salix*, and *Shepherdia* is recorded in clay older than $12,350 \pm 190$ B.P. By at least 11,000 B.P., the three other lakes were also accumulating pollen-rich deposits, dominated in the early stages by *Pinus contorta*, *Abies*, *Picea* and *Alnus*. The first evidence of cedar (*Thuja* and perhaps *Chamaecyparis*) history in southwestern British Columbia is presented from pollen and macrofossil analyses. Pollen of Douglas-fir began a rapid increase about 10,500 B.P. at all four lakes, probably in response to a climatic amelioration. Between approximately 10,000 B.P. and 8,000 B.P. in the Yale area, pollen assemblages suggest that the climate was relatively warm and dry, although natural succession, topography, and fires might account for the increase of non-arboreal vegetation observed in the interval. At Marion and Surprise lakes nearer the

coast, palynological evidence of a similar xerothermic interval is slight, probably reflecting an ameliorating oceanic influence. Evidence of warm and dry conditions is restricted to this period between 10,000 B.P. and 8,000 B.P., in contrast to the classical concept of a Hypsithermal interval between 8,500 and 3,000 B.P. in the Pacific Northwest.

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I have left my supervisor, Dr. G.E. Rouse, until last because I do not have space to thank him adequately. Instead, I would like to close with the following:

One rainy morning in May,
A student arrived at Point Grey,
He knocked at the house
Of professor Glenn Rouse
And left saying "This is my lucky day!"

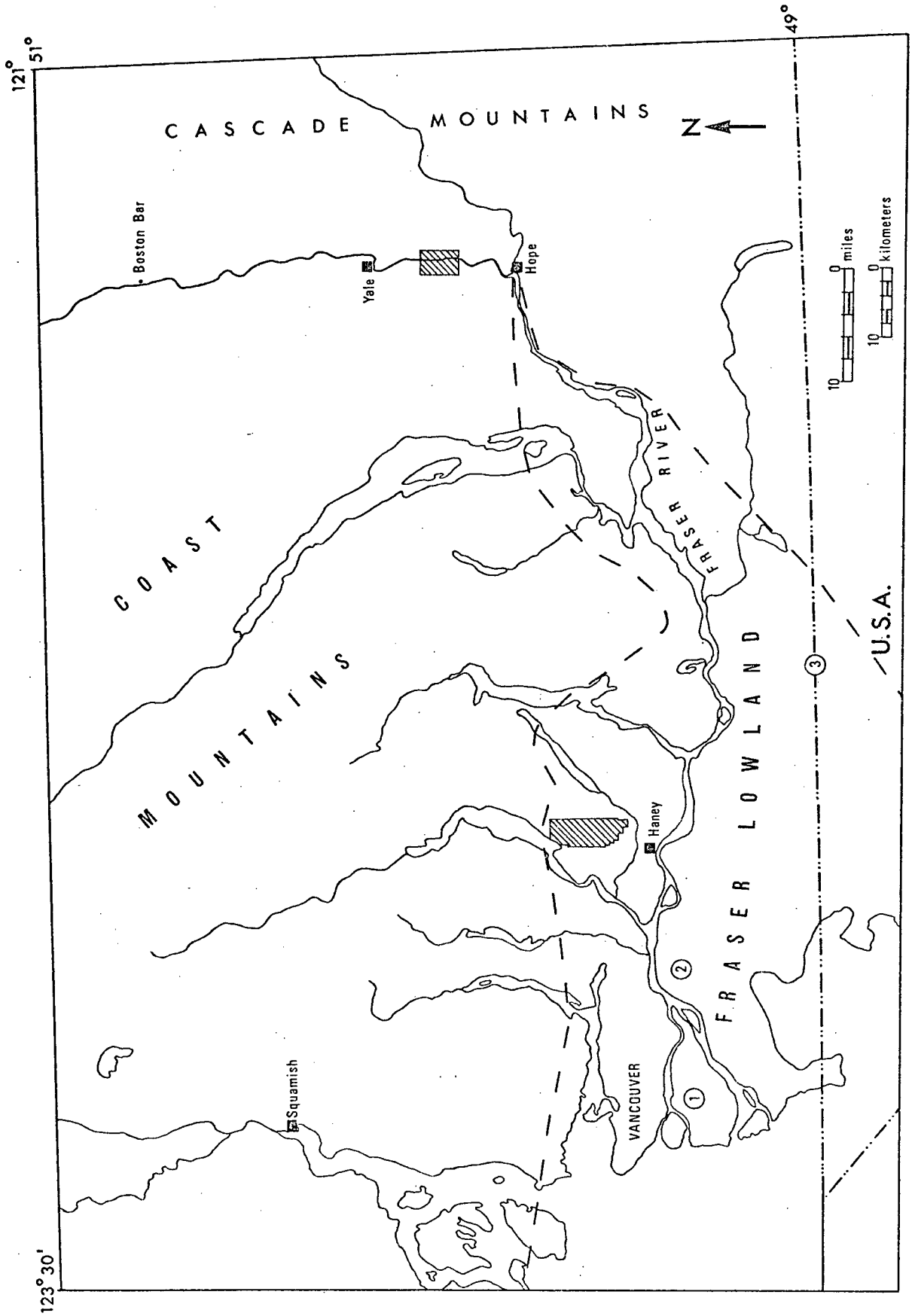
INTRODUCTION

The Fraser Lowland (Fig. 1) is a triangle-shaped part of the Georgia Lowland. It differs from the latter by having a depositional rather than erosional origin (Holland 1964). The Fraser Lowland is bounded on the north by the Pacific Ranges of the Coast Mountains, and on the southeast by the Cascade Mountains. It includes the Fraser River Delta, where sedimentary deposits up to 4,570 m thick overly granitic basement rocks (Holland 1964). Here the sediments range in age from Upper Cretaceous to recent, many containing macroscopic plant remains as well as pollen and spores.

Glacial activity during the Pleistocene radically modified the topography of the Lowland. Much of the area was depressed below present sea level (Mathews *et al* 1970), many valleys and depressions were carved by ice, and a complex of tills, outwash, glacio-marine, and marine deposits was formed. With retreat of the Vashon ice sheet about 13,000 years ago, and subsequent isostatic rebound, parts of the Fraser Lowland became available for recolonization by terrestrial plants.

The main purpose of this study is to reconstruct the history of postglacial vegetation in this area from the early colonizing stages to the present. Pollen analysis has proven to be the most successful technique for tracing the development of vegetation in many parts of the world. In this study it is supplemented by macrofossil analysis and radiocarbon dating of important sediment levels. Absolute pollen analysis is also used to complement standard percentage analyses at two of the four study sites.

Fig. 1. Map of southwestern British Columbia showing the two study areas (crosshatched). Dashed line shows approximate boundary of Fraser Lowland. Numbered circles show palynological study sites of previous workers: 1 and 2, (Hansen 1940), 3 - Pangborn Lake (Heusser 1960).



The present investigation is based mainly on four lake-sediment cores obtained from two separate localities in the Fraser Lowland region. The principal research area is the University of British Columbia (U.B.C.) Research Forest north of Haney; the second is situated between Hope and Yale, outside the Fraser Lowland proper (Fig. 1). The Yale area was chosen for its archaeological importance and its location near the transition from the coast rainforest to the drier Interior of British Columbia. Comparison of pollen diagrams from these two areas should make it possible to distinguish between pollen fluctuations of a regional nature, and those that reflect only local changes near the lake basins.

Species names and authorities used in this study follow Hitchcock *et al* (1955-1969) for vascular plants and Crum *et al* (1965) for bryophytes (see Appendix).

PART I

PALEOECOLOGY OF POSTGLACIAL SEDIMENTS FROM
THE UNIVERSITY OF BRITISH COLUMBIA RESEARCH
FOREST.INTRODUCTION

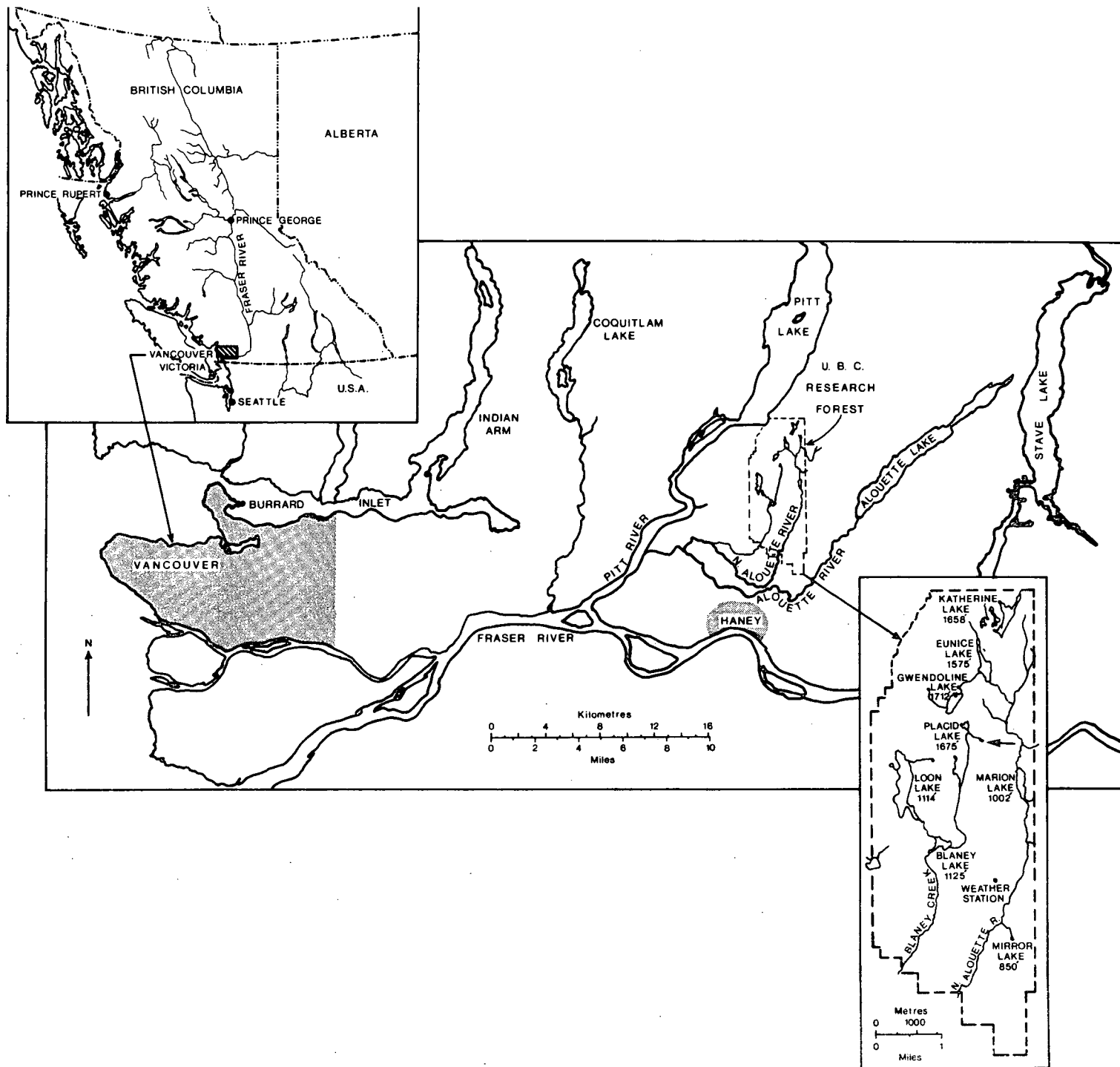
The primary aim of this investigation is to establish a detailed account of postglacial vegetation changes for the U.B.C. Research Forest, and to place observed changes within an absolute chronological framework, using radiocarbon dating.

A related objective is to try and evaluate whether observable shifts in pollen frequency are attributable to macroclimatic changes or to related phenomena such as natural forest succession, soil maturation or fires. In the past it has been difficult to ascribe primary importance to any single factor, although classically, most long-term changes tend to be interpreted as resulting from climatic fluctuations. Hansen (1940) and Heusser (1960) studied peat deposits in the Fraser River Valley (cf. sites 1, 2, 3, Fig. 1) and both indicated that postglacial climatic changes have probably taken place. The present study is an attempt to enhance and refine these interpretations by utilizing percentage and absolute pollen analyses, macroscopic subfossil analysis, and radiocarbon dating.

THE STUDY AREA

The U.B.C. Research Forest is an ecologically well-studied area about 50 km east of Vancouver and north-northeast of the village of Haney (Fig. 2). It is approximately 3,960 hectares

Fig. 2. Map showing location and drainage pattern of the U.B.C. Research Forest. Arrow (inset) points to Surprise Lake.



(9,800 acres) in area and includes a number of accessible lakes potentially suitable for pollen analysis.

The bedrock underlying the Forest is mainly granodiorite and quartz diorite, commonly mantled by glacial till and outwash deposits of variable thickness and extent. Fossiliferous marine deposits occur in the southwestern corner of the Forest. Topography is variable, but about 86% of the area can be described as hilly to mountainous (Lacate 1965). Elevations range from sea level at Pitt Lake to 790 m (2,600') north of Loon Lake (Fig. 2).

Most of the Forest is included within the Coastal Western Hemlock Zone (CWHZ) as characterized by Krajina (1969 p. 35). Annual precipitation in this zone ranges from 165 - 665 cm (65 - 262") and the mesic soils are podzolic. In the U.B.C. Forest the primary tree species are western hemlock (*Tsuga heterophylla*), western red cedar (*Thuja plicata*), and Douglas-fir (*Pseudotsuga menziesii* var. *menziesii*). Less common are grand fir (*Abies grandis*), lovely fir (*A. amabilis*), western white pine (*Pinus monticola*), yellow cedar (*Chamaecyparis nootkatensis*), and Sitka spruce (*Picea sitchensis*). Logging, fires, and other disturbances tend to promote angiosperm trees, with the result that red alder (*Alnus rubra*), broadleaf maple (*Acer macrophyllum*), and vine-maple (*A. circinatum*) are locally abundant.

Eis (1962) has shown that extensive fires occurred in the U.B.C. Research Forest in 1550, 1660, and 1770. Other major fires were recorded about 1840 and in 1868, and logging began in 1921. Subsequent burns were recorded in 1925, 1926, and

1931 (Lacate 1965).

STUDY SITES

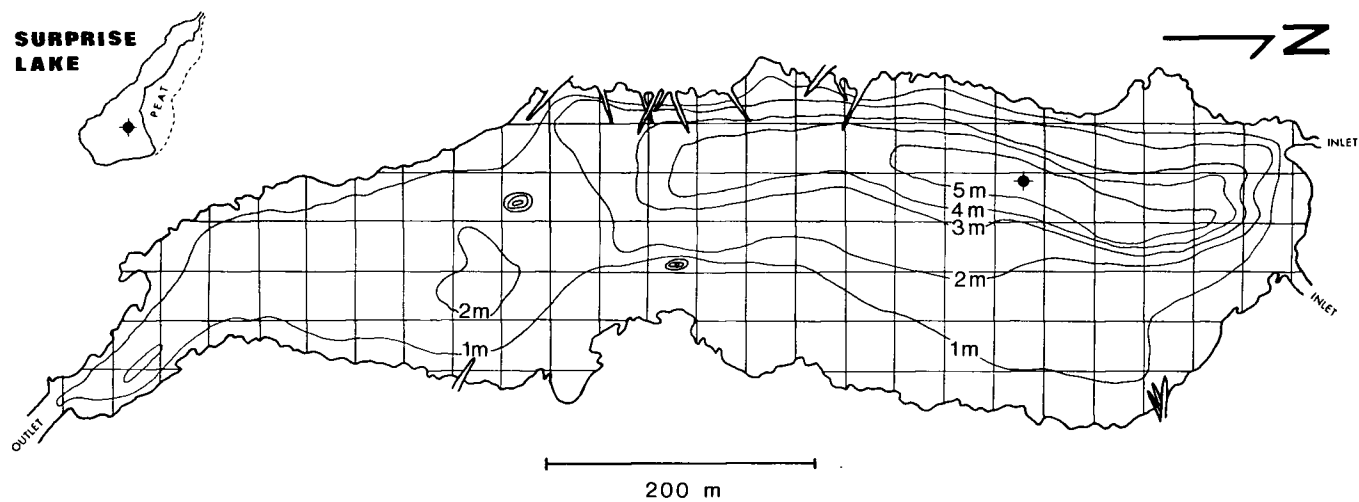
Two lakes were investigated in this study. Marion Lake (Fig. 2) was chosen because it is part of an International Biological Programme study of ecosystem dynamics. The lake occupies a valley depression at 305 m (1,002') elevation, and is 800 m long and about 200 m across at its widest point (Fig. 3). It has a permanent inlet stream at the northern end and a permanent outlet. Maximum depth fluctuates between about 5 m and 7 m. A detailed description of the lake and its physiochemical features is given in Efford (1967).

Surprise Lake is a small, boggy pond (Plate 1) located about 1 km due northwest of Marion L. (Fig. 2 arrow). Its approximate size and shape relative to Marion L. is shown in Fig. 3. The lake occupies a depression on a ridge of bedrock at an elevation of about 540 m (1,775') and is drained by an intermittently dry overflow outlet. Although Surprise L. is very small, water depth reaches about 5.6 m at one point. *Sphagnum* peat deposits ring the lake, but are most extensive on the northern shore.

Scattered yellow cedar trees growing near the water's edge indicate that this locality lies within the wet subzone of the CWHZ. Marion L. can probably be included in the wet subzone also but it may lie in a transition between the dry and wet subzones (Klinka 1973).

Surprise L. was chosen to serve as a point of comparison for Marion L. Because of their proximity, regional vegetation changes should be reflected in pollen diagrams from both sites.

Fig. 3. Morphometric map of Marion Lake. The size and shape of Surprise Lake relative to Marion L. is also shown, along with the locations of coring sites (black dots) for both lakes.



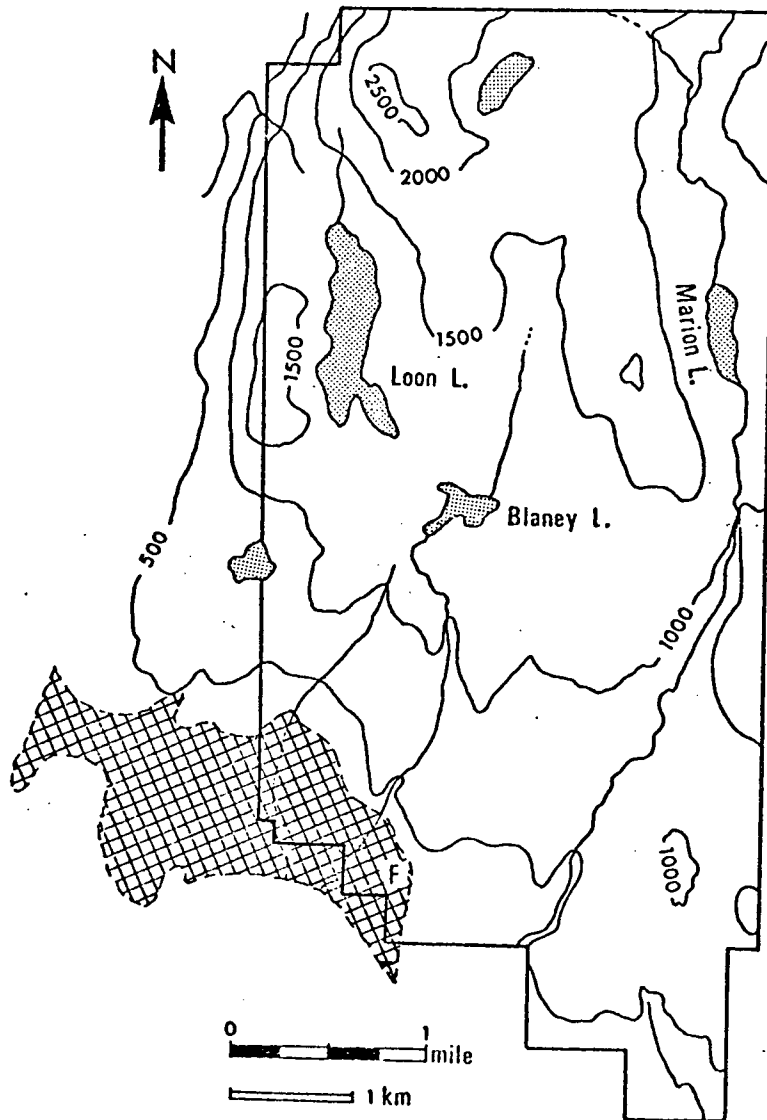
In contrast, local differences in vegetation and drainage would be expected to produce variations peculiar to each site.

A complex of sands, silts, and clays mapped as Whatcom glacio-marine deposits (Armstrong 1957) occupy the southwestern corner of the U.B.C. Research Forest (Fig. 4). In 1970, marine shells were discovered in a fresh roadcut at about 107 m (350') elevation. A sample of pelecypod shells was collected for radiocarbon dating, and the shell-bearing silty clay was sampled for pollen analysis.



Plate 1. The Surprise Lake basin, looking west-northwest toward a partially logged ridge. The vegetation near the lake is successional, consisting mainly of young western hemlock, red cedar, and ericaceous shrubs. The drooping foliage of a yellow cedar tree is visible at the extreme right of the picture.

Fig. 4. Southern end of the U.B.C. Research Forest showing extent of Whatcom glacio-marine deposits (crosshatched) and fossil site (F). After Armstrong (1957). Contours in feet.



METHODS

FIELD METHODS

Lake deposits were chosen for this study because pollen grain preservation is generally better than in peats (Faegri & Iversen 1964). Also, limnic sediments can easily be cored with a piston sampler. Core samplers (as opposed to side-wall samplers) minimize sediment distortion and provide uncontaminated samples large enough for radiocarbon dating.

Coring sites for both lakes were located in the deepest parts of the basins (Fig. 3) in order to obtain as complete a sequence of postglacial sediments as possible. Sampling was carried out between two boats bolted together with steel cross-bars, and stabilized with four concrete anchors. A casing of 3-inch aluminum irrigation pipe (Mott 1966) was used to prevent excessive bending of the extension rods as the sampler was pushed into the sediment.

The water-sediment interface and upper meter of sediment were collected using a Brown sampler (Mott 1966 Pl. IV). Deeper sediments were collected in approximately one-metre sections, using a square-rod piston sampler with a sampling tube 5 cm in diameter (Wright 1967). Each core segment was extruded in the field, measured, wrapped in aluminum foil, labelled and placed in a core-box. The cores were then frozen and stored in preparation for laboratory analysis.

LABORATORY METHODS

In order to gain as much information as possible from the sediment samples, laboratory preparation followed a scheme that would allow for calculation of absolute pollen concentrations as well as standard pollen percentages.

The uppermost meter of each core was extruded from its sample tube while frozen and cut into 5 cm long samples. These were placed into beakers and thawed in preparation for subsampling. A calibrated plastic 2 cc syringe was modified and used to extract 1 cc "plugs" from the core segments. Five such plugs constitute a sediment subsample (Plate 2-A). Each subsample was oven-dried at 70° C for 24 hours, and then weighed to the nearest .1 mg. The mean dry weight for five replicate subsamples from a sample of homogeneous sediment from Marion L. was calculated as $1.0317 \pm .0534$ grams with a standard deviation of 5.2% of the mean. Subsampling accuracy is reduced somewhat in regions where the sediment is coarse or fibrous. Lower sections of the core were thawed without sectioning and also subsampled at 5 or 10 cm intervals. After subsampling, the core segments were re-wrapped and frozen.

Each subsample was treated using a standard technique that included boiling in 5% KOH, screening, HF and acetolysis. The remaining residue was dehydrated in an alcohol series, mixed with silicone oil, and the resulting mixture was weighed to the nearest .1 mg. After thorough mixing, a small drop of the silicone oil with residue was placed on a tared microscope slide and also weighed to .1 mg. A round coverslip was then placed

over the drop and the slide sealed with molten paraffin. The area under each coverslip was then systematically scanned under 400X magnification and all pollen and spores identified and counted.

The above procedure was modified from Traverse and Ginsburg (1966 p. 427), who give the following formula for computing microfossils per gram of sediment:

$$X = \frac{\frac{B}{C} D}{A}$$

where: X = no. of microfossils per gram
 A = grams of sediment sample
 B = total grams of maceration residue plus mounting medium
 C = grams of residue plus mounting medium on slide
 D = total number of microfossils on slide

This formula can be modified to also give the number of microfossils per cubic centimeter of wet sediment (X_{cc}) because the original volume of each subsample was 5 cc:

$$X_{cc} = \frac{\frac{B}{C} D}{5}$$

Thus by starting with a known volume of sediment, it is possible to gain a maximum amount of information from this procedure. The same slides used for calculating absolute pollen concentrations can also be used to calculate relative pollen frequencies.

When the pollen analyses from both lakes were completed, the cores were again thawed and samples for radiocarbon analysis were taken to date particular changes in the pollen diagrams

and to calculate sedimentation rates. Zones containing macroscopic plant remains were screened, and wood, foliage, cones, seeds and mosses were saved for identification.

RESULTS

STRATIGRAPHY

Sediment cores 8.9 m and 5.2 m long were obtained from Marion and Surprise lakes respectively. The stratigraphy of each core is summarized at the left of their respective pollen diagrams (Fig. 5 and Fig. 6). The whole Surprise L. core and most of the Marion L. core consist of gyttja, a mixture of plant fragments, diatom frustules, mineral grains and animal remains, together with pollen and spores (Plate 2-B). Fresh gyttja from Marion L. is generally olive-brown in colour, changing rapidly to black on exposure to air. Surprise L. sediment is more brownish by comparison, indicating the probable presence of humus colloids derived from the surrounding peat deposits. The colour indicates that Surprise L. sediment is at least transitional to dy, a gyttja mixed with unsaturated humus colloids (Hansen 1959).

Considerable amounts of silt and fine sand are present in the Marion L. core, whereas both are rare or absent in Surprise L. samples.

At the base of the Marion L. core, gyttja grades rapidly into a blue-gray clay of undetermined depth. No clay was found in Surprise L., suggesting that the earliest postglacial sediments may be missing from this basin.

A conspicuous characteristic of the Marion L. core is the intermittent presence of layers of heterogeneous plant debris and sand, here termed detritus zones. They vary in thickness from about 1 - 15 cm and range from compact debris to gyttja interspersed with lesser amounts of detrital material.

It is clear that much of the material in the Marion L. detritus zones is allochthonous in origin, brought in by the stream and perhaps by slopewash. Charcoal fragments were detected in a thin detritus zone 15 cm below the gyttja-water interface, indicating that at least some of the zones could have formed in response to erosional runoff following fires.

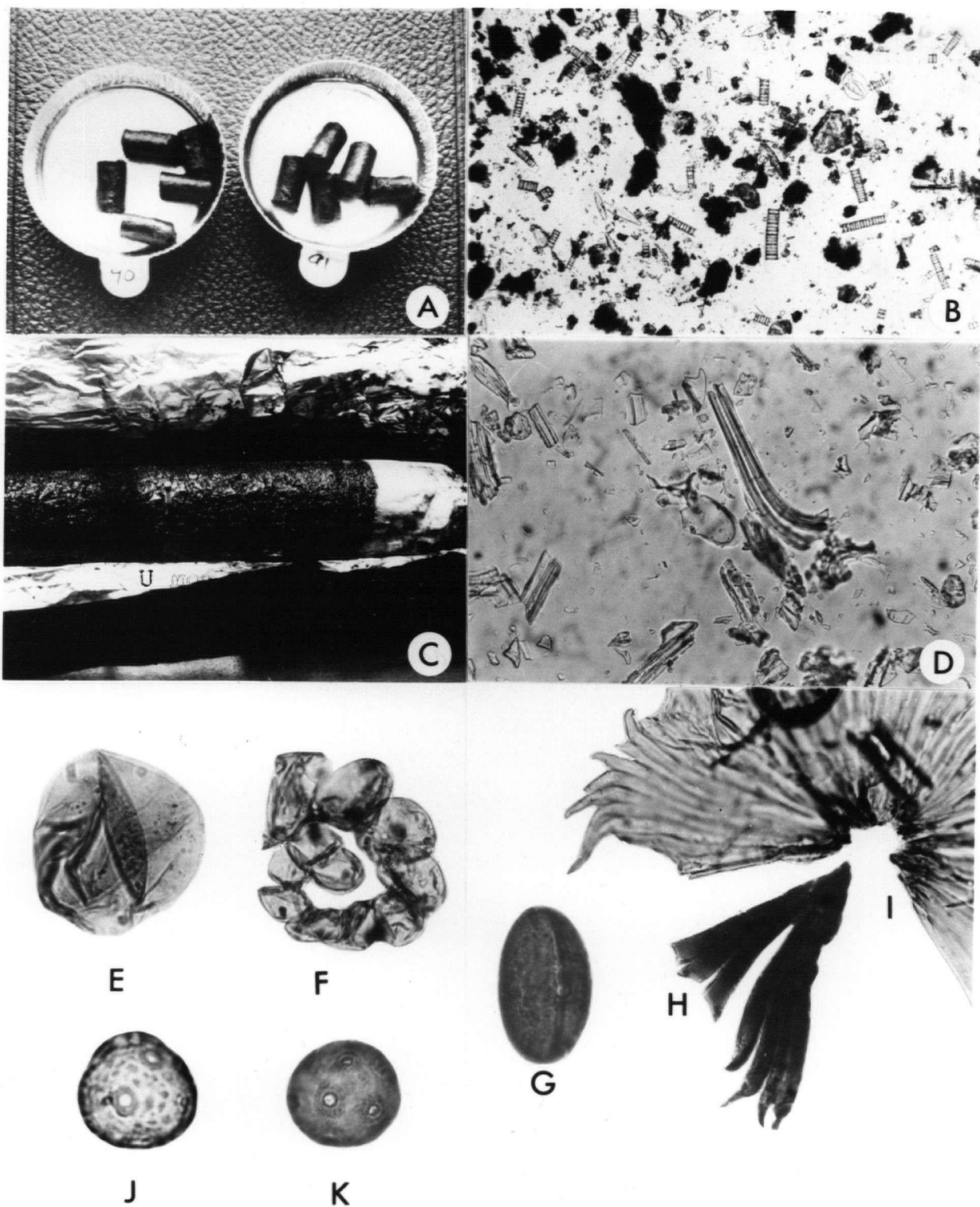
The macrofossil remains, which include well-preserved mosses in most detritus zones, will be discussed in detail later.

A single layer of white volcanic ash was encountered in each core. At Marion L., the ash forms a compact layer 5 cm thick (Plate 2-C), whereas in Surprise L. it is 3.5 cm thick. Microscopic examination revealed glass shards typical of volcanic ash deposits (Plate 2-D).

The occurrence of a distinct volcanic ash layer in postglacial bogs of Washington State has been known for many years (Hansen 1947a). More than 200 bogs in Washington are known to contain such an ash layer, mistakenly ascribed to an eruption of Glacier Peak by Hansen (1947a) and Rigg and Gould (1957). Powers and Wilcox (1964) have used petrographic and chemical characteristics to correlate this postglacial ashfall in the Pacific Northwest with the eruption of Mount Mazama (Crater Lake) about

Plate 2

- A. Two 5 cc gyttja subsamples before oven-drying.
- B. Photomicrograph of gyttja from Marion Lake, ca. 100X.
- C. Portion of Marion Lake sediment core showing 5 cm thick layer of Mazama volcanic ash at right.
- D. Photomicrograph of Mazama ash from Marion Lake, 450X.
- E. Pollen grain of *Thuja-Chamaecyparis* type, 900X.
- F. Chitinous test of microforaminiferan from U.B.C. Forest marine clay deposit, 450X.
- G. Pollen grain of *Shepherdia canadensis* from Marion Lake pollen zone ML-1, 900X.
- H. Portion of a peltate elaeagnaceous trichome (cf. *Shepherdia*) from Marion Lake pollen zone ML-1, 300X.
- I. Part of a modern peltate trichome of *Shepherdia canadensis* from the U.B.C. Herbarium, 300X.
- J. Pollen grain of *Plantago lanceolata* from zone ML-5, 900X.
- K. Pollen grain of *Sarcobatus* type from Marion Lake, 900X.



6,600 years ago.

Although the single ash layers in Marion and Surprise lakes were not dated directly, their positions relative to radiocarbon dates of sediment above and below confirm their Mazama origin.

RADIOCARBON DATES AND SEDIMENTATION

Heusser (1960) has pointed out the need for chronological control in pollen-stratigraphic correlations in the Pacific Northwest. Variations in sediment types and sedimentation rates hinder comparisons of pollen diagrams from various deposits, necessitating the establishment of an absolute time-scale. In this study, 14 radiocarbon dates were used to determine the age of each deposit, the times of major fluctuations in the pollen diagrams, and the sedimentation rates between successive dates.

A large sample of pelecypod shells (mainly *Macoma* sp.) was separated from the marine clay described earlier. The outer 65% of the shells was removed with HCl prior to dating, and a radiocarbon age of $12,690 \pm 190$ (I-5959) was determined. This date compares closely to the early part of postglacial time in the western and central Fraser Lowland (Mathews *et al* 1970, Fulton 1971). The "postglacial" as used in this study begins with the time that any site in question became free of glacier ice.

Eight radiocarbon samples from Marion L. and five from Surprise L. were also submitted for dating to Teledyne Isotopes

Inc., New Jersey. The results are summarized in Table I.

The basal radiocarbon dates indicate that organic sedimentation began in Marion L. about 1,100 years earlier than in Surprise L. It is unlikely that such an age difference could be due to different times of deglaciation for each basin because the lakes are only 1 km apart. The lack of a basal clay layer in Surprise L. suggests that local physiographic factors could account for the absence of the earliest sediments. Although no direct evidence is available, a landslide from the steep slope on the northern edge of the lake may have dammed the basin around 11,230 years ago, allowing sediment to accumulate. Tectonic disturbances associated with postglacial rebound may also have affected the drainage of the basin.

The calculated sedimentation rates for both lakes (Table I) indicate large differences, both within each lake, and between lakes. Particularly noticeable is the higher rate of sediment accumulation above the volcanic ash layer in Marion L. compared to Surprise L. Sedimentation rates in Marion L. were also more variable (.026 - .146 cm/yr) than in Surprise L. (.024 - .073 cm/yr.)

Intervals of rapid sedimentation in Marion L. are usually associated with detritus zones, where sediments apparently accumulated more rapidly than in the interbedded gyttja. For example, the interval between $4,860 \pm 105$ B.P. and $4,035 \pm 105$ B.P. exhibits both the greatest concentration of fibrous material and sand, and the highest sedimentation rate (.146 cm/yr).

Table I. Carbon-14 dates and sedimentation rates from Marion and Surprise lakes, British Columbia.

Depth (cm)	Isotopes Inc. Sample number	Radiocarbon age* Years before 1950	Sedimentation rate (cm/yr.)
MARION LAKE			
20-25	I - 6833	520 ± 115	.043
47.5-52.5	I - 5961	890 ± 90	.074
180-185	I - 6832	2,140 ± 125	.106
330-335	I - 6823	4,035 ± 105	.079
450-455	I - 6822	4,860 ± 105	.146
600 V. ash		6,600	.085
700-705	I - 6821	7,645 ± 340	.093
810-867	I - 5960	12,350 ± 190	.026
SURPRISE LAKE			
55-65	I - 6964	1,555 ± 130	.039
130-140	I - 6965	4,715 ± 100	.024
245 V. ash		6,600	.058
305-315	I - 6966	8,275 ± 135	.037
455-465	I - 6967	10,340 ± 155	.073
515-520	I - 5816	11,230 ± 230	.065

*All errors are one standard deviation

Because sedimentation rates in both lakes are so variable, one cannot assume a constant rate even within each dated interval. Hence the interpretation of absolute pollen data is much more difficult and speculative than would be the case if sedimentation rates were uniform.

ABSOLUTE POLLEN CONCENTRATIONS

Concentrations of pollen and spores per cc of wet sediment are plotted for Marion and Surprise lakes in Figs. 5 and 6 respectively. A notable feature is the generally much higher palynomorph content of Surprise L. sediment. For example, around 10,370 B.P. in Surprise L., the pollen and spore concentration is about 160,000 per cc, and in Marion L. only 35,000 per cc. The magnitude of these differences is variable, and in this case can be partly attributed to the detritus in the Marion L. sample. Sharp drops in pollen concentrations can be observed wherever a detritus zone was sampled, supporting the idea that detritus accumulates more rapidly than gyttja. If detritus zones are formed during periods of high runoff, then the selective removal of fine particles, including pollen and spores, would also contribute to lower pollen concentrations.

Similarly, the presence of the inlet stream probably accounts for the comparatively low pollen concentrations of Marion L. gyttja. It has been estimated that during heavy rainstorms the equivalent of the total lake volume may be flushed out in less than 2.3 days (Efford 1967). If Marion L.

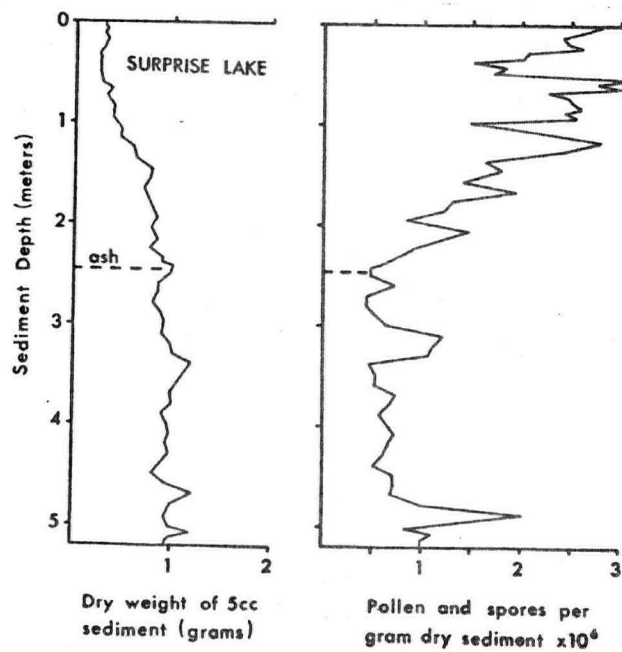
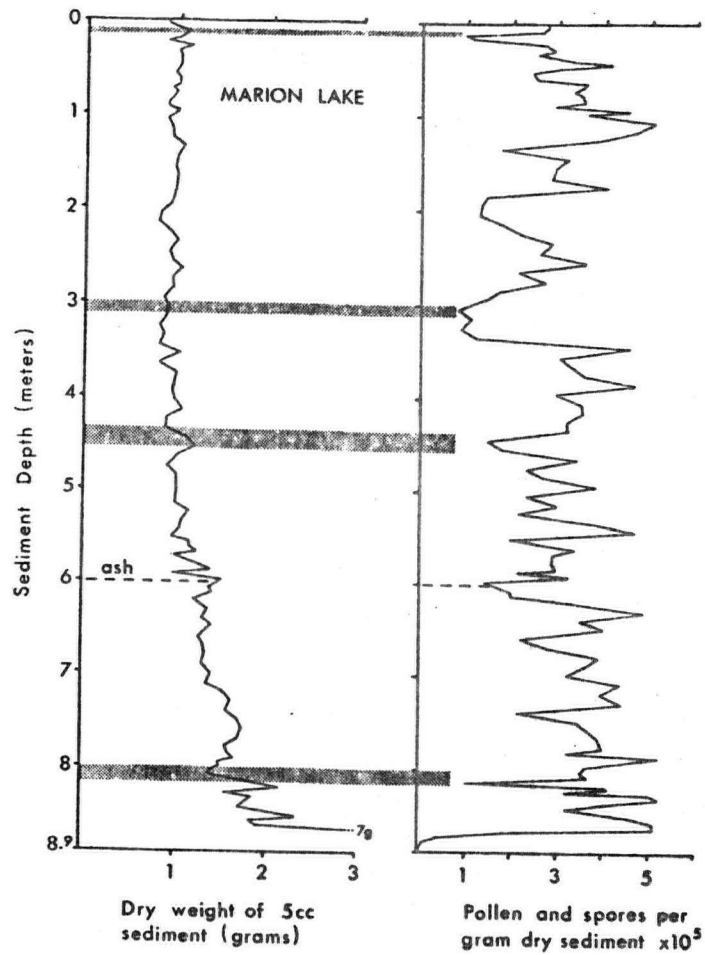
undergoes significant pollen resuspension and redeposition (Davis 1968), then such flushing is likely to remove pollen and spores that had previously settled as well as palynomorphs just introduced to the system. The higher palynomorph concentrations in Surprise L. sediment would therefore seem to reflect more accurately the pollen production of the surrounding vegetation.

Palynomorph concentrations can be expressed in grains per gram of sediment as well as per volume of sediment (cf. Traverse and Ginsburg 1966). Fig. 7 shows the weight of 5 cc oven-dried sediment relative to the pollen concentration per gram for Marion L., and Fig. 8 for Surprise L.

As expected, Marion L. detritus zones are characterized by sharp decreases in pollen per gram, paralleling the figures for pollen and spores per cc. Other highs and lows also tend to correspond between curves of pollen per cc and pollen per gram, although not always proportionately. For example, in Marion L. the pollen content per cc of sediment at 8.6 m is about 2.7 times as high as at 1 m. For the same two levels, numbers of pollen per gram of sediment are about the same. From the sediment dry weight curve in Fig. 7 it is clear that the lower-than-expected value of pollen per gram at 8.6 m is due to a sediment weight increase (ca. 1g to ca. 2g). Some of this weight increase can be attributed to a higher mineral content, although sediment compaction also seems to be a factor.

Fig. 7. Sediment weight and palynomorph concentrations of Marion L. sediment. Horizontal bars indicate detritus zones.

Fig. 8. Sediment weight and palynomorph concentrations of Surprise L. sediment.



At Surprise L., a similar dependence on sediment weight is shown by declining amounts of pollen per gram as sediment weight increases from the surface down to the ash layer (Fig. 8). These examples indicate that factors other than sedimentation rate sometimes affect pollen concentrations in gyttja.

In view of the variability of sedimentation rates and sediment densities within these lakes, absolute pollen diagrams for individual species such as those given by Davis and Deevey (1964) or Ritchie (1969) would not be meaningful. These findings concur with the conclusions of Faegri and Iversen (1964 p. 103) that absolute pollen contents of peats and sediments are too dependent on the nature of the deposit to be generally applicable.

POLLEN AND SPORE IDENTIFICATION

Identifications of subfossil palynomorphs were made using a modern pollen and spore reference collection prepared from Pacific Northwest species. Descriptions of certain pollen types given by Hansen (1947a) and Heusser (1960) were also consulted, and for the identification of common circumboreal taxa, Erdtman *et al* (1961, 1963) proved useful. Where some uncertainty exists regarding the stated affinity of any pollen or spore, the identification is followed by the designation "type", following the practice of Janssen (1967).

A major deficiency in all previously published pollen diagrams from the Pacific Northwest is the lack of data on pollen of the Cupressaceae, generally considered to be

poorly preserved in peat deposits (Hansen 1940, Heusser 1960). Preliminary inspection of gyttja samples from Marion and Surprise lakes, however, revealed generally good preservation of cupressaceous pollen, here designated *Thuja-Chamaecyparis* type (Plate 2-E). The abundance of *Thuja plicata* in the U.B.C. Research Forest indicates that most pollen frequency fluctuations, particularly at Marion L., are probably attributable to this species.

Although pollen of the maples is usually grouped under *Acer* sp., in this study all identifications have been extended to species using the criteria of Helmich (1963).

The long-standing problem of separating the pollen of *Pinus* species by size-range methods has been discussed by Mack (1971). He found considerable geographic variation in the pollen size of *Pinus contorta*, *P. ponderosa*, *P. monticola* and *P. albicaulis*, and concluded that the size-range method is not accurate enough to distinguish them. Pollen of the yellow pines (*P. contorta* and *P. ponderosa*) can however be easily distinguished from the white pines on a morphological basis (Ting 1965).

Yellow pine pollen encountered in this study is designated as *Pinus contorta* type because *P. ponderosa* is a species restricted to the dry interior of B.C., and probably never grew in the study area. Also, macrofossils from both Marion and Surprise lakes indicate that *Pinus contorta* is the represented species. Macrofossil evidence from Surprise L. and modern distribution patterns also suggest that the white pine pollen

is assignable largely to *Pinus monticola*. Pollen grains of *Abies* and *Picea* have not been identified to species because the size-range method of Hansen (1947a) is probably subject to the same criticisms given by Mack (1971) for *Pinus*. Until more reliable pollen identification methods are available, it appears advisable to avoid specific determinations for these and certain other genera to minimize the possibility of errors in paleoecological interpretations.

PALYNOLOGY OF MARINE CLAY

Recovery of palynomorphs from the marine deposit is considered significant because of the nature of the material as well as its age ($12,690 \pm 190$ B.P.), which is greater than the earliest dated gyttja from either lake. Although it is 340 years older than the first-formed organic sediment in Marion L., the marine clay contains an abundance of pollen and spores, listed in Table II. Rare pollen types encountered after the original count of 500 grains was completed include *Tsuga heterophylla*, *Shepherdia canadensis*, Gramineae, Compositae (Tubuliflorae), and *Typha latifolia*. The predominance of *Pinus contorta* type would be expected in an early postglacial environment, although the high figure of 91% probably indicates some overrepresentation of this species.

This marine pollen assemblage corresponds very closely to one described by Terasmae and Fyles (1959) from an approximately 12,000 year old marine deltaic deposit on Vancouver Island. Both assemblages seem to indicate that pollen from

Table II. Pollen and spore assemblage from marine clay
(12,690 \pm 190).

TREES AND SHRUBS	% of total pollen and spores counted (500)
<i>Pinus contorta</i> type	91
<i>Abies</i>	1
<i>Picea</i>	1.2
<i>Tsuga mertensiana</i>	.4
<i>Alnus</i>	1.6
ANGIOSPERMS	
<i>Artemisia</i>	.8
Polygonaceae	.4
Onagraceae	.2
Compositae (Liguliflorae)	.2
Unknown	.4
CRYPTOGAMS	
Monolete Polypodiaceae	1.4
<i>Polypodium vulgare</i> type	.8
<i>Cryptogramma</i>	.2
<i>Lycopodium annotinum</i>	.2
<i>Selaginella wallacei</i> type	.2
Total pollen and spores per cc wet sediment - ca. 5,000	
Total pollen and spores per gram dry sediment - ca. 3,000	

these deposits reflect the presence of nearby successional vegetation. Reworking of older Pleistocene deposits is an unlikely source for these pollen and spores because grains observed in this study were both well-preserved and abundant. Long-distance dispersal may account for some of the palynomorphs, but in view of their concentration of 5,000 per cc, a local origin is more plausible. Whether the observed pollen concentration reflects abundant or sparse terrestrial vegetation is unknown, and only a detailed study of modern marine deposits in the Fraser Lowland area could provide a means of comparison and interpretation.

Chitinous inner linings of microforaminifera (Plate 2-F) were also observed in the marine clay preparation. Such microfossils serve to confirm the marine origin of sediments (Faegri and Iversen 1964); unfortunately it is not possible to derive data on water temperature or salinity from them.

POLLEN DIAGRAMS

The basic sum used for relative frequency (%) calculations includes pollen and spores of all non-aquatic plants except fungi. Pteridophyte spores are included because many species are important members of coast rainforest communities. For the majority of pollen spectra, between 500 and 1,000 pollen and spores were counted. Spectrum (sample) numbers are given on each pollen diagram (Figs. 5 and 6) for purposes of reference and discussion. Percentages of each taxon are plotted on two scales in both diagrams. Black curves indicate calculated percentages and the accompanying grey curves show a 10X exaggeration of the true percentage values. This method was chosen to indicate fluctuations in the relative abundance of rare pollen types.

For discussion purposes, the pollen diagrams are divided into informal pollen assemblage zones, using the convention of designating each zone by the initials of the site (cf. Cushing 1967, Janssen 1968). Thus the Marion L. zones are prefixed by ML- and Surprise L. zones by SL-. This pollen assemblage approach was chosen in preference to the geologic-climate units used by Heusser (1960, 1964) for the Pacific Northwest.

THE MACROFOSSIL RECORD

Paleoecological interpretations will be enhanced by a joint comparison of the pollen and spore record with the record of wood, foliage, cones, seeds, and subfossil bryophytes.

In Surprise L., needles of *Pinus contorta* were consistently present in the basal gyttja ($11,230 \pm 230$ B.P.) up to the $10,340 \pm 155$ B.P. level. Another notable feature is a small macrofossil zone at 135 cm. depth ($4,715 \pm 100$ B.P.) containing five-needle fascicles of *Pinus monticola* as well as *Thuja plicata* foliage. Other significant macrofossil concentrations were not observed, although scattered fragments of *Thuja* foliage were common in the upper 1.5 meters of sediment.

The detritus zone areas of Marion L. sediment yielded diverse assemblages of macrofossils, summarized in Table III. Identifications of vascular plants were checked with modern material from the U.B.C. Vascular Plant Herbarium and with descriptions in Hitchcock *et al* (1955-1969) and Hosie (1969). Bryophytes were identified by W.B. Schofield, Department of Botany, U.B.C.

Most of the macrofossils probably originated from vegetation growing close to the lakeshore or along the inlet stream. The high degree of cellular preservation, even of delicate mosses, suggests that transport of this material prior to burial was not extensive. All the macrofossil taxa identified during this study can still be found growing in the U.B.C. Forest today.

Of special interest are occurrences of a number of sub-fossil bryophyte assemblages between 10,370 B.P. and about 3,600 B.P. Twenty-two species have been identified from 10 levels (Table IV) and a number of other specimens have not

Table III. Marion Lake macrofossils (except mosses).

pollen spectrum nos. see Fig. 5	<i>Tsuga heterophylla</i> foliage	<i>Thuja plicata</i> foliage	<i>Abies</i> - type foliage	<i>Pinus contorta</i> foliage	<i>Alnus</i> cf. <i>rubra</i> wood	<i>Dulichium</i> (Cyperaceae seeds)	Fern pinnules
41	+	c+	+				
47-49	+	c+s	+			+	
54-55	+	s+	+		+	+	
62-63	+	s+	+			+	
66	c+		+				
73-75	+		+			+	+
----- V. ash							
76-78	c+w		*+		+	+	
84	+					+	+
88	+					+	
99-100	+	s+				+	
113-114				+			

+ = present, c = ovulate cone, s = seed(s), w = wood,

* = bract from *Abies amabilis* cone.

Table IV. Occurrence of bryophyte subfossils in Marion
Lake sediment.

	Pollen spectrum (sample) numbers See Fig. 5
<i>Antitrichia curtipendula</i>	99-100, 73-75, 66, 62-63, 54-55, 41
<i>Bartramia pomiformis</i>	54-55
<i>Dendroalsia abietina</i> *	73-75
<i>Dichodontium pellucidum</i>	84, 73-75
<i>Dicranella palustris</i>	66
<i>Dicranum fuscescens</i>	47-49
<i>Eurhynchium praelongum</i>	73-75, 66, 47-49
<i>Heterocladium macounii</i>	47-49
<i>Homalothecium fulgescens</i> *	62-63
<i>Hylocomium splendens</i>	73-75, 66, 54-55
<i>Hypnum circinale</i> *	73-75
<i>Hypnum subimponens</i>	66
<i>Isothecium stoloniferum</i> *	99-100, 84, 76-78, 73-75, 66, 62-63, 54-55, 47-49
<i>Leucolepis menziesii</i> *	62-63
<i>Mnium insigne</i> *	66
<i>Neckera douglasii</i> *	73-75
<i>Porotrichum bigelovii</i> *	66
<i>Rhytidiadelphus loreus</i>	73-75, 66, 62-63, 54-55
<i>Sphagnum magellanicum</i>	62-63
<i>Sphagnum palustre</i>	99-100, 76-78, 41
<i>Sphagnum papillosum</i>	99-100, 88, 66, 54-55
<i>Sphagnum subsecundum</i>	54-55, 47-49

* - Western North American endemic

been recorded because of uncertainties in identifications. As in other paleoecological work, only the presence of a species in a particular sample is significant. Absence from a sample has no diagnostic value unless it is tied in with a broad regional record.

The presence of *Isoethecium stoloniferum* in the majority of macrofossil zones is a significant discovery. This species is a Western North American endemic, and is "...largely restricted to the humid coastal climatic area and associated with coniferous forest or vegetation that precedes closed coniferous forest." (Schofield 1969 p. 162). The other species in Table IV are also extant in the area of the U.B.C. Forest today. Although they are more sporadic in the core than *Isoethecium*, they contribute to the tentative suggestion that since about 10,370 years ago, the climate and vegetation of the study area have been of a humid coastal type.

The time of 10,370 B.P. corresponds to a period of change in the pollen diagrams from both lakes, allowing the ecological interpretations based on macrofossils to be checked against those suggested by the corresponding pollen assemblages.

POLLEN ZONATION

The pollen diagrams from Marion and Surprise lakes have been arbitrarily divided into zones containing distinctive pollen assemblages. The Marion L. core was divided into five zones, and Surprise L. into three. Such zones aid in

discussions of changes in the diagrams, and correlating similar events between lakes. Until further work is done, however, they should not be considered as typical for the whole Fraser Lowland area. Some of the changes are local in nature, and only further study and comparison can determine if any of these zones can be correlated over wider areas.

MARION LAKE (Fig. 5)

Zone ML-1 (spectra 116-112, older than 12,350 B.P.)

This narrow basal zone is characterized by rapidly rising percentages for *Pinus contorta* type, terminating with peak values for pine (90%). *Salix* pollen is relatively high, and *Alnus*, *Artemisia* and Polypodiaceae are also represented. Pollen of *Shepherdia canadensis* (Plate 2-G) is the best indicator for the zone, reaching a value of 14% at the base. Because *Shepherdia* is insect-pollinated and a low pollen producer, a value of 14% is very significant. The presence of trichome fragments (Plate 2-H) comparable in shape and size to modern *Shepherdia* trichomes (Plate 2-I), confirms the identification and indicates that the shrubs probably grew near the site of deposition. Similarly, abundant *Pinus contorta* needles in the clay of zone ML-1 indicate that this species also grew at the lake.

As with *Alnus* spp., the presence of nitrogen-fixing bacteria in the roots of *Shepherdia canadensis* (Stewart 1967) probably aids this species in colonizing immature soils. *Shepherdia canadensis* is found on poor soils in semi-open

forest areas throughout British Columbia, except in the wet coastal strip. In Manning Park, about 150 km east of Vancouver, it grows together with *Pinus contorta* and other seral species at elevations of around 1,200 m (Plate 3). This observation suggests that cool, continental conditions probably prevailed in the Marion L. area for the duration of zone ML-1.



Plate 3. *Shepherdia canadensis* (right centre) growing together with lodgepole pine in Manning Park, B.C., at approximately 1,200 m elevation. The shrub on the left is snowbrush (*Ceanothus velutinus*).

Low absolute pollen concentrations at the base of this zone (640 per cc) rise very quickly to about 140,000 per cc at the top (ca. 12,400 B.P.), suggesting a rapid rate of colonization by pine and other species. This is not surprising in view of the indication from the older marine clay that the same species were already present in the southern U.B.C. Forest area around 12,690 \pm 190 B.P.

Zone ML-2 (spectra 112-102, ca. 12,400 -ca. 10,500 B.P.)

At the transition from zone 1 to zone 2 the percentages of *Pinus contorta* pollen start to decrease. This decline is steady and is accompanied by concomitant increases of *Abies*, *Picea*, *Tsuga mertensiana*, *Alnus*, and fern spores. Trace amounts of *Tsuga heterophylla* appear in the lower parts of the zone and increase at the transition to zone 3. The pattern observed here suggests a natural succession, with more shade-tolerant conifers starting to replace lodgepole pine in favourable sites. A postglacial amelioration of climate may have contributed to this replacement process, although the small peak of *Tsuga mertensiana* at the top of the zone points to generally cool and moist conditions. The average sedimentation rate for this zone is very low (.026 cm per year), making this interval appear too narrow in relation to the rest of the pollen diagram. The termination of this interval just prior to 10,370 \pm 145 B.P. corresponds closely to the date of 10,500 B.P. designated by Heusser (1960 p. 179) as the boundary between the Late-Glacial and the Postglacial.

Zone ML-3 (spectra 102-75, ca. 10,500 - 6,600 B.P.)

The sudden appearance of abundant *Pseudotsuga* pollen around 10,370 \pm 145 B.P. marks the beginning of this interval. Maximum values for Douglas-fir (11%) occur in the bottom part of the zone. Also recorded are decreases in *Pinus contorta*, *Abies*, *Picea*, and *Tsuga mertensiana*. *Tsuga heterophylla* values increase slowly at the beginning, reaching about 27% just below the Mazama ash. *Alnus*, monolete fern spores, and *Pteridium aquilinum* spores reach their highest levels in this zone. A number of angiosperms including *Corylus*, *Quercus*, and *Arceuthobium* are represented for the first time in this interval.

Macrofossil evidence (Table III) shows that western red cedar was already present near Marion L. around 10,000 years ago. Pollen of the Cupressaceae is very rare and scattered at this time, suggesting that the macrofossils were probably derived from the initial immigrants to the area. *Thuja*-like pollen is low throughout the zone, reaching a maximum of 1% near the Mazama ash, a natural upper boundary for the zone.

Zone ML-4 (spectra 75-4, 6,600 - ca. 500 B.P.)

Above the ash layer, the percentages of Cupressaceae pollen rise erratically to about 40% at spectrum 18. *Tsuga heterophylla* reaches its highest values (ca. 40%) in the lower half of the zone and declines to about 20% at the top. This apparent drop in *Tsuga* corresponds to increases in *Thuja*-

Chamaecyparis type pollen. Foliage, cones, and seeds of *Thuja plicata* are also abundant in this interval (Table III), and clumps of cedar pollen were sometimes observed, possibly indicating local concentrations of trees along the lakeshore and inlet stream. Skunk cabbage (*Lysichitum americanum*) is a common associate of *Thuja* in seepage sites, and its pollen increase in the upper part of this zone suggests that paludification may have contributed to more favourable growth of red cedar around Marion L.

Pinus contorta type is consistently present in low amounts (less than 5%) and *Pinus monticola* type is more consistently and strongly represented here than in lower zones. *Abies* pollen is slightly more abundant than in most of ML-3. The only indication of the species of fir is an ovulate cone bract of *Abies amabilis* from the uppermost part of ML-3. This species requires very wet climates with constantly moist soils (Krajina 1969 p. 59), and can be used as an indicator for the wet subzone of the Coastal Western Hemlock Zone.

Pseudotsuga pollen is present throughout the zone in low amounts, and *Alnus* representation is between 20 and 35%. The abundance of fern spores fluctuates around 10%.

Zone ML-5 (spectra 4-1, ca. 500 B.P. to the present)

ML-5 is a short zone reflecting vegetation changes that have occurred since about 520 ± 115 B.P. *Alnus* percentages increase from 25% to about 40%, and *Betula*, Rosaceae, and *Pteridium* record small increases. In the uppermost sample

(0-5 cm), grass pollen reaches its highest level for the whole core (3.5%) and three pollen grains of the introduced weed *Plantago lanceolata* (Plate 2-J) were found. Corresponding decreases are indicated for the dominant conifers, *Tsuga heterophylla* and *Thuja-Chamaecyparis* type. From the patterns observed here, it is clear that the decrease in climax species and increase of successional types started about 500 years ago, well before commercial logging started in the area.

The presence of charcoal chunks up to 1.5 cm long in the sediment of samples 2, 3, and 4 (5-20 cm) indicates that fire has played a role in these vegetation changes. A detritus zone at 10-15 cm contains the greatest concentration of charcoal and sand, and by extrapolation from the underlying date of 520 ± 115 B.P., an approximate age of 330 yrs. B.P. is derived for the start of this layer. This date is significant in view of Schmidt's (1957 p. 7) findings that around 300 yrs. ago, a fire of gigantic proportions consumed about 2,000,000 acres of forest on Vancouver Island. He states further that fires also occurred on the Mainland coast at this time, although their extent is less known. Eis (1962), however, has shown that a major fire occurred in the U.B.C. Research Forest around 1660 A.D., perhaps initiating the formation of this Marion L. charcoal zone.

SURPRISE LAKE (Fig. 6)

Zone SL-1 (spectra 67-59, 11,230 - ca. 10,500 B.P.)

Pinus contorta is abundant at the beginning of this zone (60%) and declines slowly to about 47% at the top. Needles of lodgepole pine occur throughout the sediment of this interval. *Abies* and *Picea* percentages are greater than 1% and *Tsuga mertensiana* reaches 1.5% at the upper boundary. *Alnus* pollen ranges between 27 and 49%, and *Tsuga heterophylla*, *Artemisia*, and *Pteridium* are present but not abundant.

The lower boundary of SL-1 (11,230 \pm 230 B.P.) is much younger than the beginning of ML-2 (ca. 12,400 B.P.) Both on chronological and palynological grounds, the start of SL-1 correlates approximately with Marion L. spectrum no. 106. The upper limit is placed at around 10,500 B.P., based on a date of 10,340 \pm 145 just above the designated boundary. From radiocarbon dates and conifer pollen curves, the upper boundaries of SL-1 and ML-2 correlate almost exactly, indicating a synchronous regional vegetation change.

Zone SL-2 (spectra 59-41, ca. 10,500 - 7,700 B.P.)

This zone begins with a sudden increase of *Pseudotsuga* pollen, rapidly reaching a peak value of 13%. *Abies*, *Picea*, and *Tsuga mertensiana* values drop in the early part of SL-2, and *Pinus contorta* type declines slowly throughout this interval. *Tsuga heterophylla* pollen is less than 5% for the lower two-thirds of the zone, increasing to about 20% at the

upper boundary. *Thuja-Chamaecyparis* type is low and *Alnus* is high throughout. *Pteridium* rises to a maximum of 14% near the top of the zone, and monolete Polypodiaceae occur at less than 3%.

Curves for conifer pollen in zone SL-2 generally correlate well with those of ML-3. Percentages of *Pinus contorta* type, however, are consistently higher at Surprise L., probably reflecting local differences in elevation, topography and soils between the two sites. Similarly, the abundance of monolete fern spores in ML-3 (12-40%) can probably be ascribed to the valley position of Marion L., where rich soils and abundant moisture promote fern growth. The more rugged terrain and shallow soils of the Surprise L. area provide fewer suitable sites for ferns (except Bracken), and this difference seems to be reflected in the pollen diagrams.

Zone SL-3 (spectra 1-41, ca. 7,700 B.P. to the present)

This zone is characterized by rising percentages of *Thuja-Chamaecyparis* type. Cedar pollen is low (2%) at the start of the zone, but increases to a maximum of 68% at 1,555 \pm 130 B.P. A decline to 48% is recorded from 1,555 B.P. to the present. Higher percentages of cedar pollen are reached at Surprise L. than at Marion L., perhaps due to heavier growths of cedar at the water's edge. Scattered fragments of *Thuja* foliage were commonly observed in the upper 1.5 m of sediment, where pollen percentages were also highest.

Pollen of *Pinus contorta* type is low within this interval, as is *Pinus monticola* type. Western white pine, however, is a good indicator for this zone since it is usually represented at 1% or more. In lower zones it is usually absent, but may occur sporadically at frequencies less than 1%. Other taxa represented most strongly in SL-3 include *Betula*, *Acer macrophyllum*, *Quercus*, and *Lysichitum americanum*.

There is no strong indication of ecological disturbance in the most recent sediments. A small peak of *Pteridium aquilinum* and low *Tsuga heterophylla* percentages suggest that fire or logging may be reflected in the uppermost gyttja, although the distinct changes associated with ML-5 are not evident.

DISCUSSION AND CONCLUSIONS

The results of this investigation indicate that soon after the Vashon ice started to retreat from the Fraser Lowland about 13,000 years ago, vegetation quickly recolonized the deglaciated terrain in the area of the U.B.C. Research Forest. By 12,690 \pm 190 B.P., a fairly diverse palynomorph assemblage dominated by *Pinus contorta* type pollen was preserved in a marine clay. Whether these early immigrants to the Fraser Lowland existed only along a near-ocean strip or also in upland areas is unknown.

Marion L. at 305 m elevation was ice-free sometime before 12,350 \pm 190 B.P., when pollen of lodgepole pine, *Shepherdia canadensis*, willow and alder were deposited in clay underneath the first dateable organic sediment. The

earliest organic sediments record abundant lodgepole pine pollen associated with fir, spruce, and mountain hemlock until about $10,370 \pm 145$ B.P. Cool and moist conditions are indicated for this interval which seems to record the replacement of shade-intolerant lodgepole pine by more shade-tolerant conifers. High percentages (31% of total alder) of 4-pored alder grains from this period suggest that mountain alder (*Alnus incana*) may have been present in the U.B.C. Forest at this time.

The sudden appearance of abundant Douglas-fir pollen around 10,500 years ago at Marion and Surprise lakes is associated with decreases in lodgepole pine, fir, spruce, and mountain hemlock. A trend toward warmer and perhaps somewhat drier conditions at this time may have favoured Douglas-fir, but high alder pollen with macrofossils of *Thuja* and *Isoethecium stoloniferum* indicate abundant moisture.

Between about 10,500 B.P. and the approximate level of the Mazama ash layer at 6,600 B.P., the pollen diagrams record a successional type of vegetation with Douglas-fir, alder, bracken fern (*Pteridium aquilinum*) and declining lodgepole pine. Western hemlock was present during the early part of this interval, but did not increase strongly until about $8,275 \pm 135$ B.P. at Surprise L., and about 7,300 B.P. at Marion L. This "lag phase" of western hemlock development has been previously noted in Puget Sound, where its slow expansion was partly attributed to increased postglacial warming and drying (Hansen 1947a p. 82).

In the U.B.C. Research Forest, the slow rise of western hemlock percentages may not reflect a primary influence of climate. An alternate explanation may reflect the fact that *Tsuga heterophylla* grows best on podzolized soils, and regenerates most effectively on mor humus or decaying conifer wood (Krajina 1969). It is conceivable, therefore, that the early spread of hemlock was dependent on the formation of edaphic sites favourable for its growth. This explanation has also been suggested by Hansen (1950) for the slow increase of western hemlock on southeastern Vancouver Island.

The percentages of western hemlock continue to increase at the ash layer, where hemlock wood, foliage, and an ovulate cone occur in the Marion L. core. The same macrofossil horizon contains a well-preserved bract from an ovulate cone of *Abies amabilis*, indicating heavy precipitation around 6,600 B.P. *Isoethecium stoloniferum* subfossils above and below the ash support the interpretation that humid coastal conditions prevailed at this time.

Thuja macrofossils indicate that western red cedar was present in the U.B.C. Forest about $10,370 \pm 145$ B.P., although low numbers of cedar pollen suggest that these trees were rare until about 6,600 B.P. Above the ash layer, cedar pollen reaches maximum percentages of 43% in Marion L. and 68% in Surprise L. At Surprise L., both red and yellow cedar are probably represented in the diagram, whereas at Marion L. the present vegetation and abundant macrofossils in the sediments indicate that red cedar was the major contributor of

cupressaceous pollen.

Since the same general trends of increasing *Thuja-Chamaecyparis* pollen are observed at both lakes, they are not likely to be artifacts of differential pollen preservation. Examination of cedar pollen from various spectra indicate that although abundance differs, the preservation of individual grains is not markedly different between surface and deeper samples. Comparable trends of cedar pollen are also present in two lakes about 90 km east of the U.B.C. Forest, and Easterbrook (1971) has mentioned the presence of a *Tsuga heterophylla*-Cupressaceae zone above an ash layer in Puget Lowland bogs.

Climatically, the combined dominance of hemlock and cedar above the Mazama ash indicates wet, mesothermal conditions approximating those of the present. This interpretation is supported by the diverse subfossil moss assemblages from Marion L., consisting totally of species that occur in the U.B.C. Forest area today.

The inferred pattern of *Pinus monticola* immigration into the U.B.C. Forest differs noticeably from the pattern described by Hansen and Heusser for the Pacific Northwest. Hansen (1947a p. 79) stated that western white pine was next in importance to lodgepole pine as an early postglacial invader. Heusser (1960 p. 133) mentions the tendency of white pine percentages to follow the trend of the lodgepole pine profiles. These trends are not apparent in the Marion and Surprise L. profiles, where *Pinus monticola* type is virtually absent before 10,000 B.P.,

and does not reach values greater than .7% below the Mazama ash layer. It's maximum representation above the ash is 6.2% at spectrum 24 from Marion L. Whether these differences represent biogeoclimatic differences or differences in identification methods is difficult to assess.

Although oak pollen (cf. *Quercus garryana*) is present in some samples from Marion and Surprise lakes, this species does not occur in the U.B.C. Forest today. The presence of oak pollen has been used by Hansen (1947a) and Heusser (1960) to indicate warmer and/or drier conditions in parts of Oregon and Washington during postglacial time. In this study, however, the low amounts of oak pollen were probably derived from scattered stands of Garry oak growing in edaphically dry sites in the Fraser Lowland area. Even under the present climatic regime, *Quercus garryana* can grow in this area as shown by a population of oak on Sumas Mountain, about 30 km southeast of the U.B.C. Forest.

An enigmatic phenomenon in the Marion L. pollen diagram is the occasional occurrence of *Sarcobatus* type pollen (cf. spectra 15, 63, 95, & 113). These grains (Plate 2-K) are virtually identical to extant pollen of *Sarcobatus vermiculatus* (greasewood), a shrub of alkaline areas in deserts or grasslands. It does not occur in British Columbia, but grows in the dry eastern part of Washington State. The presence of these grains in sediments of the humid coast must be a result of long-distance dispersal, since the ecological requirements of greasewood do not coincide with the vegetation indicated by

the rest of the pollen assemblage. Long-distance dispersal has also been inferred for sparse amounts of *Sarcobatus* and *Ephedra* pollen in northwestern Minnesota (McAndrews 1966).

XEROTHERMIC THEORY IN THE NORTHWEST

This theory assumes that there was at least one segment of time since the last major glaciation when the climate was drier and warmer than at present (Sears 1942). Although this controversial concept originated in Europe, it has also been extended to North America to explain disjunct distributions of continental plant species beyond their usual limits (Sears 1935).

Hansen (1947a) postulated the existence of a postglacial period of maximum warmth and dryness for the Pacific Northwest of North America. The strongest evidence for this stage came from the dry Columbia River Basin of eastern Washington, where pollen of xerophytes consistently reached maximum values around the Mazama ash layers in several bogs.

In the wetter Puget Lowland of western Washington, the postulated period of warm, dry climate was less strongly expressed than in the Columbia Basin (Hansen 1947b). Here, the pattern of postglacial forest development was ascribed primarily to natural succession, modified regionally by fire, soil conditions, and to a limited extent by climate.

For southeastern Vancouver Island, Hansen (1950) concluded that the warm, dry interval was not evident. The observed changes in forest composition were again ascribed to normal forest succession in response to a general amelioration of climate and soil maturation.

A xerothermic period correlated with the warm, dry interval in eastern Washington was recognized by Hansen (1955) in south-central and central British Columbia. This period was placed between 7,500 and 3,500 B.P., with a "thermal maximum" around 6,600 B.P. This climatic interpretation relied heavily on an inferred abundance of *Pinus ponderosa* pollen during the xerothermic interval. Caution must be used in evaluating these data, however, in view of Mack's (1971) findings that the size-range method of identifying *Pinus ponderosa* pollen is not reliable.

Deevey and Flint (1957) used the term "Hypsithermal" to describe a postglacial period during which mean annual temperatures in most of the world are believed to have exceeded those of the present. This concept was used by Heusser (1960), who placed the Hypsithermal between 8,500 and 3,000 B.P. in Washington State and southwestern British Columbia.

In a pollen diagram from Pangborn L. (Fig. 1, site 3) in the Fraser Lowland, Heusser (1960 Fig. 38) interpreted the Hypsithermal interval as occurring between the basal sediments at 9 meters and the 4 meter level. The base of the Pangborn L. bog was subsequently dated at $9,920 \pm 760$ B.P. (Easterbrook 1969), well before the 8,500 B.P. lower boundary for the Hypsithermal. Changes in the pollen spectra also do not seem sufficiently distinct to warrant a boundary at the 4 m level. I believe that the Pangborn L. diagram, as well as those presented in the present study, point out the lack of unequivocal palynological evidence for a Hypsithermal interval in the western Fraser Lowland. If macroclimatic changes did

occur between 8,500 and 3,000 B.P., they evidently were not of sufficient intensity to cause detectable vegetation shifts at low elevations. The generally wide tolerance ranges of most tree species together with the ameliorating oceanic influence along the coast probably masked any climatic changes; changes that would be detectable in more continental regions where temperature and moisture are often more limiting. It is not surprising, therefore, that the strongest evidence for warming and/or drying comes from continental rain-shadow areas such as the Columbia Basin and south-central British Columbia. Palynological studies by the author are presently underway in a transition area between the humid coast and the drier Interior of British Columbia to see whether or not a xerothermic influence can be detected in this region.

Another area where climatic shifts should be pronounced exists at alpine and subalpine elevations in the Coast Mountains. Evidence that timberlines were once higher than at present has been presented for parts of the Coast Mountains by Mathews (1951). Samples of *in situ* wood from tree remains collected above present timberline have been dated between $5,950 \pm 140$ and $5,260 \pm 200$ B.P. (Lowdon and Blake 1968 p. 226), probably indicating warmer temperatures at these times than prevail at present. Further work is necessary to determine how widespread these timberline shifts were, as well as the cause and duration of the inferred montane warm period. Pollen analysis and radiocarbon dating of subalpine and alpine bogs or lakes in the Coast Mountains may supply some answers to this

problem.

Pollen diagrams from Marion and Surprise lakes also seem to indicate that vegetation disturbance was common during postglacial time. The continuously high percentages of alder are especially significant, as are the pollen of the pines, Douglas-fir, willow, birch, hazel, broadleaf and vine maples, various ferns and other shrubs and herbs.

Fires have probably played an important role in the history of Pacific Northwest forest vegetation (Isaac 1940, Hansen 1947b, Schmidt 1957, Eis 1962). Low precipitation and high temperatures during midsummer promote forest fires in this region today, even though the average annual rainfall is high. As a result of fires, or other destructive phenomena such as windstorms, insect infestations, or fungal diseases, the presence of successional species is maintained within the region.

The patterns of secondary succession following fires in the U.B.C. Forest have been described by McMinn (1951), who determined that forest regeneration patterns were controlled largely by differences in available moisture, soil, and distance from seed sources. Bracken fern (*Pteridium aquilinum*) and vine-maple occur on most parts of burned areas, and red alder quickly colonizes moist valley bottoms. In most areas, regeneration of a western hemlock-red cedar forest is rapid, making the detection of individual periods of disturbance in pollen diagrams very difficult. Even 5 cm long sampling intervals are too large to record a successional cycle from a

fire back to coniferous forest. Instead, the continual presence of large amounts of pollen from seral species is testimony that disturbances, whether of physical or biological origin, have continually influenced the postglacial forests of this area.

PART II

PALEOECOLOGY OF POSTGLACIAL SEDIMENTS FROM
THE LOWER FRASER RIVER CANYON REGION OF BRITISH
COLUMBIA.INTRODUCTION

Results of pollen analysis of cores from two lakes in the Yale area are presented here to outline the history of post-glacial vegetation in this area, both for archaeological purposes and for comparison with similar studies to the west (Part I).

An archaeological sequence dating back to $9,000 \pm 150$ B.P. was established by Borden (1965, 1968) from excavations on terraces of the Fraser River at South Yale, British Columbia. As part of the South Yale Archaeological Project, sediment cores for pollen sanalysis and radiocarbon dating were collected from two lakes about 10 km south of the archaeological sites, in a study area between Hope and Yale (Fig. 1). Radiocarbon dates from the study area and their implications were discussed in an earlier paper (Mathewes *et al* 1972).

THE STUDY SITES

The locations of Pinecrest and Squeah lakes within the study area are shown in Fig. 9. Squeah L. occupies a depression about 205 m (675') above sea level in the western Cascade Mountains. Pinecrest L. at 320 m (1,100') elevation is located on the eastern slopes of the Coast Mountains. Both lakes are characterized by narrow, steeply sloping littoral

zones with sparse macrophytic vegetation (mainly *Nuphar polysepalum*). Maximum water depths are approximately 11.5 m at Squeah L., and 9.9 m at Pinecrest L.

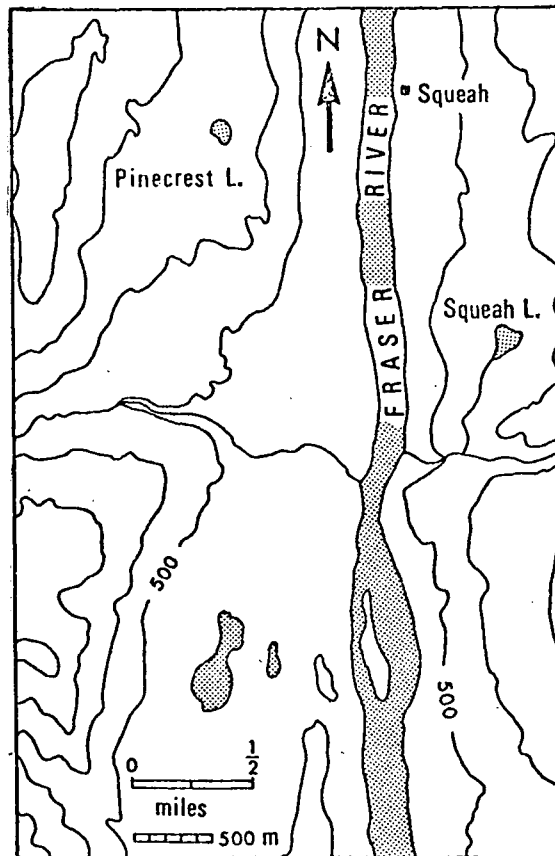


Fig. 9. Enlargement of study area in Fig. 1, showing relative positions of Pinecrest and Squeah lakes. Contour interval is 500 feet.

Forest vegetation grows to the water's edge all around Pinecrest L., leaving little room for semi-aquatic vegetation. At Squeah L., thick peat deposits occur on the western shore and a large sedge swamp occupies the outlet region. Hardhack (*Spiraea douglasii*) forms dense thickets on the drier parts of boggy areas, and grasses (Gramineae), willows (*Salix*), and Umbelliferae are locally abundant. Scattered individuals of crabapple (*Pyrus fusca*) occur in swampy areas.

Douglas-fir (*Pseudotsuga menziesii*), western hemlock (*Tsuga heterophylla*), and western red cedar (*Thuja plicata*) are the most common conifers near both lakes. White pine (*Pinus monticola*) and lodgepole pine (*P. contorta*) are also present, and several trees of grand fir (*Abies grandis*) were noted near Squeah L. The most abundant angiosperm trees in the study area are red alder (*Alnus rubra*) and paper birch (*Betula papyrifera*), although vine-maple (*Acer circinatum*), broadleaf maple (*A. macrophyllum*) and mountain maple (*A. glabrum*) are locally abundant. Black cottonwood (*Populus trichocarpa*) is common along the lower terraces of the Fraser River.

Although both lakes are situated within the Coastal Western Hemlock biogeoclimatic Zone (Krajina 1969), the study area is close to the transition between the CWHZ and the drier Interior Douglas-fir Zone. In the Fraser River Canyon between Yale and Boston Bar (Fig. 1), broadleaf maple and western hemlock disappear from the lowland vegetation and ponderosa pine (*Pinus ponderosa*) becomes noticeable near Boston Bar. Just north of Boston Bar the transition

into the Interior Douglas-fir Zone is complete. Here the annual precipitation ranges between 36 and 56 cm (14-22") and the vegetation is correspondingly more xeric in character.

METHODS

The sediment core from Pinecrest L. was taken from the side of a floating dock under 2.5 m of water, approximately 10 m out from the shoreline. The Squeah L. core was recovered at a later date from the deepest part of the lake (11.30 m) as determined by soundings with a chain and disk. A square-rod piston sampler with a coring tube 5 cm in diameter was used to collect both cores.

The Squeah L. core was taken both to obtain a basal radiocarbon date for a second lake in the area, and to provide a more complete sequence of the earliest postglacial sediments for pollen analysis. Because of time limitations, only the portion of core below the volcanic ash layer in Squeah L. was used for pollen analysis, whereas all of the Pinecrest L. core was investigated palynologically. Both cores were subsampled at 10 cm intervals to provide material for laboratory processing. Unused portions of cores were frozen and stored.

Each sediment subsample was treated with boiling 5% KOH, HF, and acetolysis to remove as much non-polliniferous material as possible. Pinecrest L. samples were stained with Safranin 'O' and mounted on microscope slides in polyvinyl alcohol (Elvanol) and Gelva resin. Samples from Squeah L. were dehydrated in alcohol and mounted in silicone oil; a more

satisfactory procedure because pollen grains can be turned on the slides for viewing at all angles.

Each slide was then scanned at 400X magnification and palynomorphs were identified and counted. Approximately 600 pollen and spores were counted for most Pinecrest L. samples, and about 500 for Squeah L. Detritus zones from the Squeah L. core were carefully screened and investigated for plant macrofossil remains and charcoal.

RESULTS

STRATIGRAPHY AND RADIOCARBON DATES

The total length of core recovered from Pinecrest L. is 4.5 m. As shown in the summary of sediment stratigraphy in Fig. 10, the deepest sediment is a blue-gray gravelly clay. A gray-green clay-gyttja was subsequently formed, grading up into a dark-olive gyttja containing fine fibers (perhaps root-lets). Gyttjas oxidize quickly to a dark colour on exposure to air, suggesting that this sediment may have formed in shallower water, where periodic oxidation could have taken place. Just below the ash layer, the sediment becomes lighter in colour and less fibrous. Fine-grained olive gyttja makes up the rest of the core.

A 2 cm thick layer of white volcanic ash occurs at 3.86 m. Chemical analysis of the ash (Table V) shows that it correlates with the eruption of Mt. Mazama, 6,600 years ago.

The Pinecrest L. pollen diagram indicates that approximately 4,400 years of postglacial time are represented by only 72 cm

Table V. Volcanic ash analyses. Recalculated to 100%
waterfree.*

	Average Mazama (58 analyses)	Pinecrest L. sample (UA-423)	Squeah L. sample (UA-424)
SiO ₂	72.59 ± 0.27	72.17	72.56
TiO ₂	0.48 ± 0.02	0.44	0.47
Al ₂ O ₃	14.42 ± 0.16	14.55	14.48
FeO (total iron)	2.08 ± 0.06	2.15	2.16
MgO	0.54 ± 0.08	0.62	0.59
CaO	1.71 ± 0.09	1.66	1.64
Na ₂ O	5.15 ± 0.16	5.45	5.15
K ₂ O	2.70 ± 0.06	2.77	2.76
Cl	0.18 ± 0.02	0.20	0.20

*The analyses for Pinecrest and Squeah lakes were kindly supplied by Dr. J. A. Westgate, Department of Geology, University of Alberta, Edmonton. Average Mazama analyses were taken from Lichti-Federovich (1970).

of sediment below the ash layer. To obtain a longer interval that might give a more detailed picture of pollen changes in pre-ashfall time, a 6.7 m core was obtained from Squeah L.

In the Squeah L. core (Fig. 11), a 2.5 cm thick layer of Mazama ash (Table V) was encountered at 4.08 m, leaving about 2.6 m between the base of the core and the ash, thus providing the longer interval for analysis. In the Squeah L. core, sandy stringers and occasional varving were noted in the grayish basal clay-gyttja, underlain by an undetermined depth of non-organic varved clay.

Screening of detritus zones in spectra (samples) 3 and 7 revealed the presence of finely-divided charcoal as well as bryophyte remains, identified by Dr. W. B. Schofield. Spectrum 3 contained *Bryum* sp., *Dichodontium pellucidum*, and *Isothecium stoloniferum*. Well-preserved fragments of *Dichodontium pellucidum*, *Eurhynchium praelongum*, *Isothecium stoloniferum*, *Leucolepis menziesii* and *Scleropodium obtusifolium* were recovered from spectrum 7. All these mosses can be found in the same general area today. A piece of wood identified as Douglas-fir was recovered from spectrum 4.

Radiocarbon dates for the basal 10 cm of clay-gyttja in both cores were determined by Isotopes Inc., New Jersey. Pinecrest L. was dated at $11,000 \pm 170$ B.P. (I-5346) and Squeah L. at $11,140 \pm 260$ B.P. (I-6058). An age of $8,620 \pm 135$ B.P. (I-5815) was obtained for clay-gyttja between 5.60 and 5.65 m at Squeah L., allowing for calculation of the average sedimentation rate (.040 cm/yr) between this level and the base of the core.

POLLEN DIAGRAMS AND ZONATION

The procedure used in Part I for identification of pollen and spores and calculation of pollen percentages was also used in this study. True percentage curves are drafted in black, and curves indicating a 10X exaggeration of real percentages are plotted in gray for both Pinecrest (Fig. 10) and Squeah (Fig. 11) lakes.

As in Part I, the pollen diagrams are divided into informal zones to facilitate discussion of changes in the pollen profiles, and to correlate changes among lakes. Pinecrest L. zones are prefixed by PL-, and Squeah L. zones by SqL-.

PINECREST LAKE (Fig. 10)

Zone PL-1 (spectrum 46, 11,000 B.P.)

This very narrow zone is limited to the basal 10 cm of clay-gyttja from the core. It is characterized by high *Pinus contorta* type pollen (ca. 40%) and the highest amount of *Picea* pollen in the core (ca. 5%). *Alnus*, *Abies*, and *Artemisia* are also prominent in this zone, which probably appears shorter in duration than normal because of a slow rate of sediment accumulation.

A radiocarbon date of $11,430 \pm 150$ (I-6057) from basal sediment in the deepest part of the lake basin (Mathewes *et al* 1972) indicates that the earliest postglacial sediment is not included in Fig. 10, probably reflecting the position of the core on the sloping littoral area.

Zone PL-2 (spectrum 45 to Mazama ash)

The sudden appearance of abundant *Pseudotsuga* pollen, along with spores of *Selaginella wallacei* type, marks the beginning of this zone. *Tsuga heterophylla* pollen is characteristically low in this interval (less than 5%), but *Selaginella*, *Salix*, *Pteridium* and Gramineae reach their highest percentages. *Alnus* is also high in PL-2 (ca. 50%), together with *Betula* which rises from less than 1% at the base of the zone to about 25% just below the ash layer. *Artemisia* and Cyperaceae are also prominent, and *Acer glabrum* pollen, although sparse, is characteristically present.

Zone PL-3 (Mazama ash to the present)

Approximately the last 6,600 years are represented in this zone, characterized by abundant *Tsuga heterophylla*, *Pseudotsuga*, *Alnus* and *Betula* pollen. *Thuja-Chamaecyparis* type pollen is ca. 10% at the base of the zone, rising to ca. 25% in the upper half. *Pinus monticola* type is continuously represented at greater than 1%, reaching a maximum of 8% in spectrum 9.

SQUEAH LAKE (Fig. 11)

Zone SqL-1 (spectra 26-23, 11,140 - ca. 10,400 B.P.)

Pinus contorta type, *Abies*, and *Alnus* pollen predominate in this zone, together with relatively high amounts of *Picea* and *Artemisia*. Correspondence with zone PL-1 is suggested by similarities of the assemblages. The age for the upper limit

of the zone was obtained by extrapolating from the two subtending radiocarbon dates, assuming a constant sedimentation rate of .040 cm/yr.

Zone SqL-2 (spectrum 22 to Mazama ash, ca. 10,400 - 6,600 B.P.)

Correlation of this zone with PL-2 is obvious, especially in the peak percentages of Gramineae, *Artemisia*, *Pteridium*, and *Selaginella wallacei* type. Declining *Pinus contorta* type, low *Tsuga heterophylla*, rising *Betula* percentages and the appearance of abundant *Pseudotsuga* pollen at the lower boundary also correspond to PL-2.

Low amounts of *Thuja-Chamaecyparis* type at Squeah L. contrast the relative abundance of cupressaceous pollen at Pinecrest L. The higher percentages of cupressaceous pollen in Pinecrest L. are probably exaggerated, however, due to large amounts of hyaline plant debris in the basal sediments. Some of this material closely resembles the thin-walled pollen grains of the cedars, making accurate identification difficult. Increased acetolysis treatment of Squeah L. samples removed most of this debris, suggesting that the limited distribution of *Thuja-Chamaecyparis* type below the ash at Squeah L. reflects more accurately the regional vegetation picture.

The diversity and abundance of non-arboreal pollen in PL-2 is high, suggesting that forest cover was less complete than at present in the Yale area. Pollen of several herbs and shrubs not found at Pinecrest L. are present in this zone.

Rhamnaceae pollen is fairly abundant and probably includes both *Rhamnus purshiana* (Cascara) and *Ceanothus* sp.. *Philadelphus* (mock orange) type pollen was also found, along with *Shepherdia canadensis*, *Symphoricarpos*, *Epilobium*, and *Sagittaria*. Although *Sagittaria* (Indian potato) no longer grows at Squeah L., it was definitely present in pre-Mazama time.

DISCUSSION AND CONCLUSIONS

The pollen zonation patterns from Pinecrest and Squeah lakes suggest the following reconstruction of postglacial vegetation succession in the Yale area.

Following the retreat of glaciers from the study sites, sandy and gravelly meltwater clays containing little organic material were deposited in the lake basins. As plants invaded the deglaciated terrain around the lakes, pollen and spores as well as other terrestrial organic remains settled in the lake basins, together with limnic floral and faunal remains. Radiocarbon-dateable clay-gyttjas were formed as organic matter increased in the sediments, eventually grading into highly organic fine-grained gyttjas which are still being formed today.

The pioneer vegetation recorded at the bases of the pollen diagrams consists of abundant *Pinus contorta* and *Alnus*, with lesser amounts of *Abies*, *Picea*, *Salix*, *Artemisia*, and various ferns (*Polypodium*, *Adiantum*, *Cryptogramma* and others).

Climatic patterns for most pollen diagrams are difficult to assess, inasmuch as macroclimatic effects are often complicated by natural succession patterns of vegetation and

soil development. It must also be remembered that pollen analysis primarily provides data on the composition of past vegetation, and that explanations to account for these vegetation types are necessarily speculative. By analogy, however, the early postglacial vegetation seems to indicate cool and moist conditions, with *Artemisia* occupying open, well-drained areas.

At the transitions to zones PL-2 and SqL-2 about 10,400 years ago, several well-defined changes take place. *Pseudotsuga* pollen increases sharply, whereas *Pinus contorta* type decreases, suggesting a natural replacement of pine by the more shade-tolerant Douglas-fir. At the same time, pollen of grasses and spores of *Pteridium* and *Selaginella wallacei* type begin to increase, reaching peak levels around $8,620 \pm 135$ B.P. Together with *Artemisia*, Chenopodiaceae, Tubuliflorae, Rhamnaceae (*Ceanothus*) and *Philadelphus* type pollen, this assemblage indicates drier and warmer conditions than prevailed during earlier postglacial times.

The previous suggestion that water levels may have been lower at Pinecrest L. in pre-Mazama time also ties in with the suggestion of drier climatic conditions. Relatively abundant Cyperaceae pollen in PL-2 suggests that semi-aquatic sedges may have occupied shoreline areas exposed by a lowered lake level.

High *Alnus* pollen, together with increasing *Tsuga heterophylla*, *Abies* and *Betula* since about 8,500 B.P., suggest a return to somewhat wetter conditions. The subfossil mosses

recovered from Squeah L. spectra 3 and 7 also support this view, since all species can presently be found in the Yale area. Again, it is difficult to separate the natural rate of dispersal of certain genera (*Betula*, *Corylus*) from "migration" induced by climatic change.

The interval from the Mt. Mazama ash to the present is represented by zone PL-3. Basically, there is a continuation of the trend toward wetter conditions observed in the upper part of zone PL-2. *Tsuga heterophylla*, *Thuja-Chamaecyparis* type, and *Pinus monticola* type reach their highest levels here. Pollen of *Acer macrophyllum* and *Acer circinatum* are often present, whereas the more continental-montane *Acer glabrum* is absent from most samples above the ash.

It is clear from the foregoing that this study does not support a classical xerothermic interval between 7,500 and 3,500 B.P. (Hansen 1955) or a Hypsithermal between 8,500 and 3,000 B.P. (Heusser 1960). Instead, it is apparent that fairly warm and/or dry conditions prevailed during deposition of the lower parts of zones PL-2 and SqL-2, with a trend toward wetter conditions already apparent before the Mazama ash layer was deposited at 6,600 B.P. It is significant that this compares closely with evidence for a warm interval in northwestern Alaska between 10,000 B.P. and 8,300 B.P., during which forest biota expanded far beyond their present limits (McCulloch and Hopkins 1966).

This study, although providing a solid basis for the interpretation of postglacial events in the Lower Fraser Canyon region, indicates that additional research is necessary

to determine if the palynological patterns established for the Yale area can be correlated over wider areas. Also, the climatic interpretations, although based on sound evidence, must be considered tentative, as the possibility exists that the palynological indications of a warm and/or dry interval may actually reflect a stage in a longterm natural succession.

It is conceivable that due to the mountainous terrain of the Yale area, the development of a closed forest was hindered in many localities. Shallow, rocky soils together with unstable mountain slopes may have promoted the continual presence of heliophytes such as *Pteridium*, grasses, and *Selaginella*, which in more mesic and stable sites would have been quickly supplanted by forest vegetation. In addition, as indicated by charcoal fragments in the detritus zones from Squeah L., fires have also played a role in the history of the Yale area, perhaps promoting the presence of non-arboreal vegetation at many sites.

Further work, especially in the drier parts of the Fraser Canyon above Boston Bar, is necessary to establish well-dated pollen sequences for comparison with the Yale area. Only by comparing sites in different physiographic settings can we satisfactorily resolve the problems of separating climatic changes from natural successional processes controlled by local factors of topography, soil, and fire.

THESIS SUMMARY

A general summary of pollen zonations established during this study of the Fraser Lowland region is given in Table VI. In conjunction with the detailed pollen diagram from each lake, the following conclusions can be drawn:

1. The oldest polliniferous postglacial deposits so far described from south-western British Columbia are presented in this study. A marine clay with abundant lodgepole pine pollen extends the record of terrestrial vegetation in the Fraser Lowland back to 12,690 B.P. Recorded in the basal sediment from Marion L. is a previously undescribed pollen assemblage consisting of lodgepole pine, willow and *Shepherdia*. This assemblage is older than 12,350 B.P., extending the record of postglacial vegetation beyond the ca. 11,500 B.P. level established by Heusser (1960 Table 6) for south-coastal British Columbia.
2. Five pollen zones are described from Marion L. and three from Surprise and Pinecrest lakes. Two zones were recognized from the pre-Mazama sediment at Squeah L.
3. All four lakes in this study were accumulating polliniferous sediments by 11,000 B.P. Lodgepole pine, spruce, fir and alder predominated in the pioneer vegetation at all sites, with mountain hemlock reaching relatively high levels only in the U.B.C. Forest sites.
4. A synchronous vegetation change is recorded in all cores

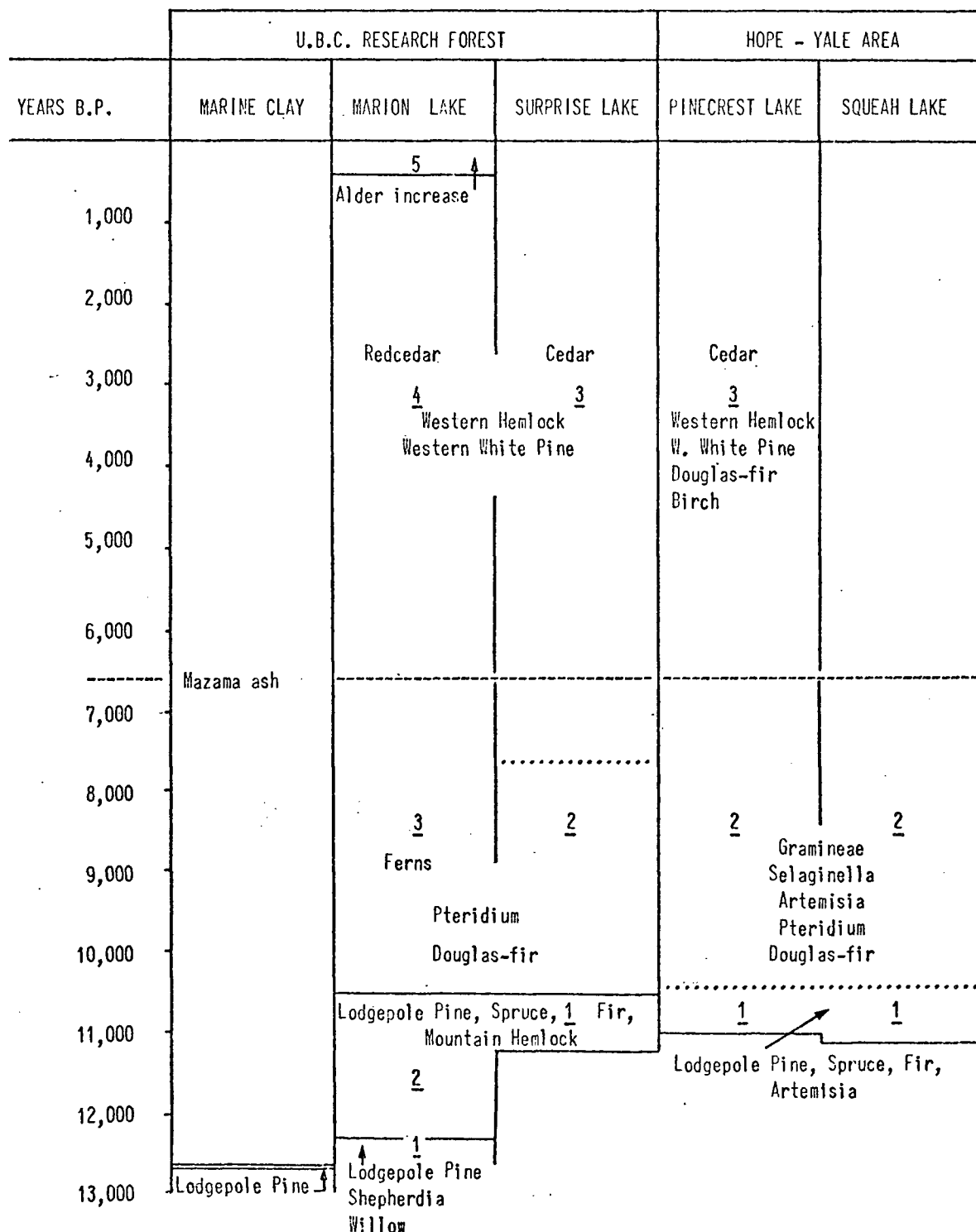


Table VI. Pollen zone correlations in the Fraser Lowland area. Horizontal solid lines indicate radiocarbon-dated boundaries; dotted lines are extrapolations from radiocarbon dates. Plants listed are assemblage indicators for each zone (see pollen diagrams for details).

around 10,500 to 10,400 B.P., when Douglas-fir pollen began to increase markedly, probably in response to a climatic amelioration.

5. Peak percentages of grass, bracken fern, *Artemisia*, and *Selaginella* in the Yale-area pollen assemblages suggest a fairly warm and dry period beginning about 10,000 B.P. and terminating before the Mazama ashfall at 6,600 B.P. The U.B.C. Forest diagrams show only a faint trace of such a xerothermic period, and subfossil mosses indicate that a typically wet coastal climate has prevailed since about 10,500 B.P. It is possible that indications of warming and drying merely reflect a stage in a natural long-term succession controlled by soil development, topography and fires.

6. The presence of a Hypsithermal interval between 8,500 and 3,000 B.P. is not clearly apparent in the pollen diagrams. Although the later part of the warm-dry interval recognized in this study overlaps the Hypsithermal as defined by Heusser, the climate was wet during most of classical Hypsithermal time.

7. This study demonstrates that although red cedar was present in the U.B.C. Forest about 10,000 B.P., it has increased in importance only during post-Mazama time. Cedar percentages (red and perhaps yellow cedar) are also highest above the ash layer in the Yale-area lakes.

8. In contrast to prior studies, western white pine was found to be unimportant as an early postglacial invader,

being most strongly represented above the Mazama ash in all areas. At Surprise L., white pine pollen is virtually absent before 6,600 B.P.

9. Although pollen of birch is relatively rare at Marion and Surprise lakes, it is abundantly represented at Pinecrest and Squeah lakes. Similarly, Douglas-fir pollen is much more strongly represented above the ash in the Yale area than in the U.B.C. Forest. Since both birch and Douglas-fir are generally more abundant in the Interior Douglas-fir Zone than in the coastal zones, their palynological patterns suggest that the presently transitional biogeoclimatic conditions in the Yale area have persisted during most of post-glacial time.

10. The presence of abundant pollen of alder and other successional species throughout postglacial time in the Fraser Lowland indicates that disturbances have always influenced the vegetation of this area.

11. Evidence of major vegetation changes during the last few centuries is restricted to Marion L. The presence of charcoal and peak percentages of alder, grasses, and other successional species indicates that fire and probably logging have played an important role in these recent changes. Both factors have certainly contributed to the striking pollen decreases of commercially important species such as western hemlock, Douglas-fir and red cedar in the surface sediments.

This study has incorporated a variety of paleoecological techniques to establish a well-dated postglacial history of forest vegetation in the Fraser Lowland region. It is hoped that my results will stimulate further researches into the paleoecology of British Columbia, because to fully understand and manage our present environment, we must recognize the successional, paleoclimatic, and biogeographic changes that have moulded its present form.

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APPENDIX

List of plant species names used in the text or on the pollen diagrams.

A. Alphabetical list of bryophytes.

Names and authorities follow Crum *et al* (1965) except for *Isothecium* which follows Schofield (1968).

Antitrichia curtipendula (Hedw.) Brid.
Bartramia pomiformis Hedw.
Dendroalsia abietina (Hook.) Britt.
Dichodontium pellucidum (Hedw.) Schimp.
Dicranella palustris (Dicks.) Crundw. ex E. Warb.
Dicranum fuscescens Turn.
Eurhynchium praelongum (Hedw.) B.S.G.
Heterocladium macounii Best
Homalothecium fulgens (Mitt. ex C. Müll.) Lawt.
Hylocomium splendens (Hedw.) B.S.G.
Hypnum circinale Hook.
Hypnum subimponens Lesq.
Isothecium stoloniferum (Hook.) Brid.
Leucolepis menziesii (Hook.) Steere ex L. Koch
Mnium insigne Mitt.
Neckera douglasii Hook.
Porotrichum bigelovii (Sull.) Kindb.
Rhytidiadelphus loreus (Hedw.) Warnst.
Scleropodium obtusifolium (Hook. ex Drumm.) Kindb. ex Mac. &
Sphagnum magellanicum Brid. Kindb.
Sphagnum palustre L.
Sphagnum papillosum Lindb.
Sphagnum subsecundum Nees ex Sturm

B. Vascular plants by families. (Hitchcock *et al* 1955-1969).

DIVISION LYCOPODIOPHYTA

LYCOPODIACEAE

Lycopodium annotinum L.
Lycopodium clavatum L.
Lycopodium indundatum L.
Lycopodium selago L.

SELAGINELLACEAE

Selaginella wallacei Hieron.

DIVISION POLYPODIOPHYTA

POLYPODIACEAE

- **Polypodium vulgare* L.
Pteridium aquilinum (L.) Kuhn

DIVISION PINOPHYTA

CUPRESSACEAE

- Chamaecyparis nootkatensis* (D. Don) Spach
Thuja plicata Donn

PINACEAE

- Abies amabilis* (Dougl.) Forbes
Abies grandis (Dougl.) Lindl.
Picea sitchensis (Bong.) Carr.
Pinus albicaulis Engelm.
Pinus contorta Dougl. ex Loud.
Pinus monticola Dougl. ex D. Don
Pinus ponderosa Dougl. ex Loud.
Pseudotsuga menziesii (Mirb.) Franco
Tsuga heterophylla (Raf.) Sarg.
Tsuga mertensiana (Bong.) Carr.

DIVISION MAGNOLIOPHYTA

TYPHACEAE

- Typha latifolia* L.

ARACEAE

- Lysichitum americanum* Hultén & St. John

SALICACEAE

- Populus trichocarpa* T. & G.

BETULACEAE

- Alnus incana* (L.) Moench
Alnus rubra Bong.
Betula papyrifera Marsh.

* Spores treated as *Polypodium vulgare* type on the pollen diagrams were probably derived from a complex of species now treated as *Polypodium glycyrrhiza* D.C. Eat., *P. hesperium* Maxon, and *P. scouleri* Hook. & Grev.

FAGACEAE

Quercus garryana Dougl.

CHENOPODIACEAE

Sarcobatus vermiculatus (Hook.) Torr.

NYMPHAEACEAE

Nuphar polysepalum Engelm.

ROSACEAE

Pyrus fusca Raf.

Spiraea douglasii Hook.

CELASTRACEAE

Pachistima myrsinites (Pursh) Raf.

ACERACEAE

Acer circinatum Pursh

Acer glabrum Torr.

Acer macrophyllum Pursh

RHAMNACEAE

Ceanothus velutinus Dougl.

Rhamnus purshiana DC.

ELAEAGNACEAE

Shepherdia canadensis (L.) Nutt.

ARALIACEAE

Oplopanax horridum (Smith) Miq.

CORNACEAE

Cornus stolonifera (Michx.)

OLEACEAE

Fraxinus latifolia Benth.

MENYANTHACEAE

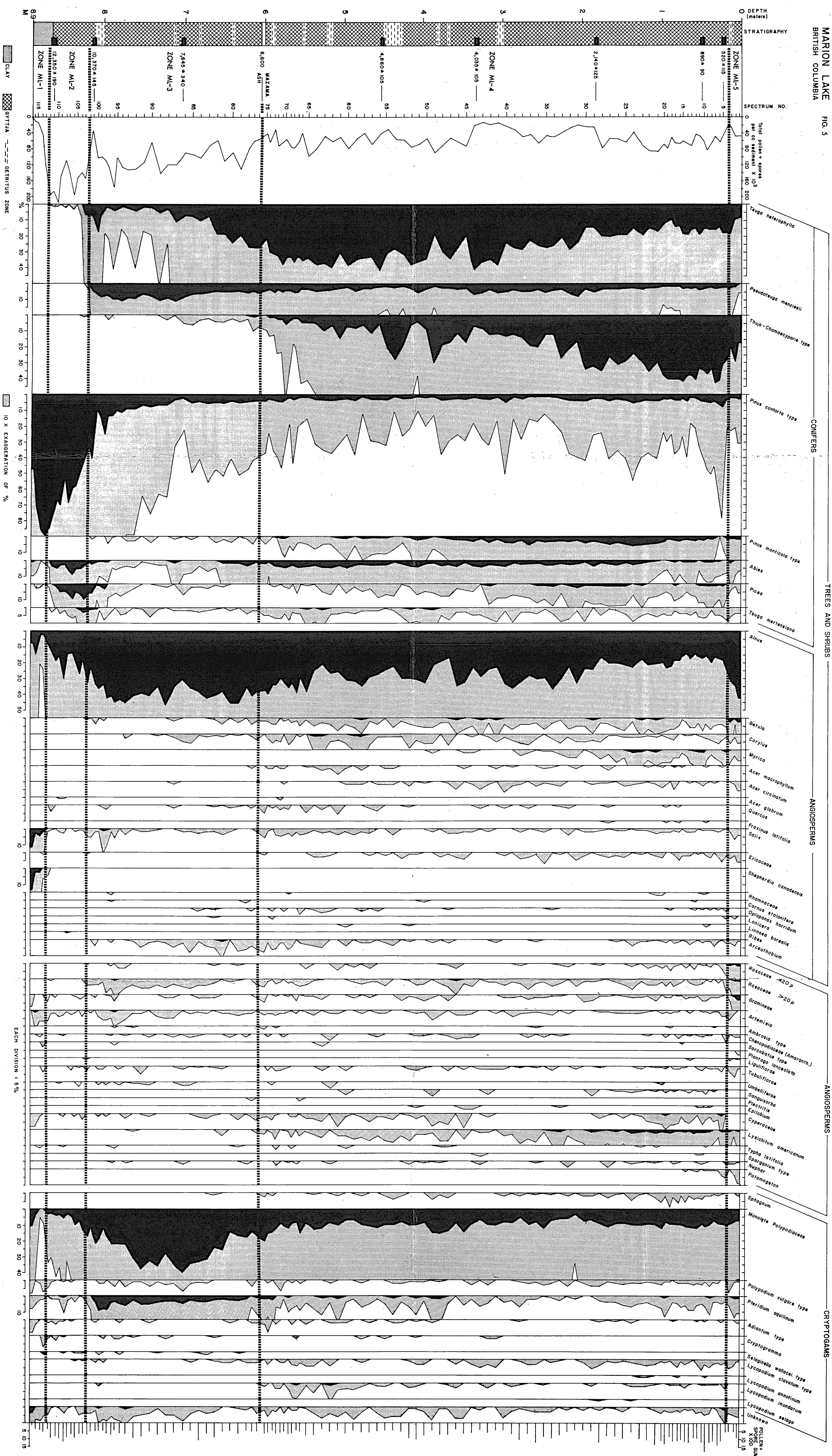
Menyanthes trifoliata L.

PLANTAGINACEAE

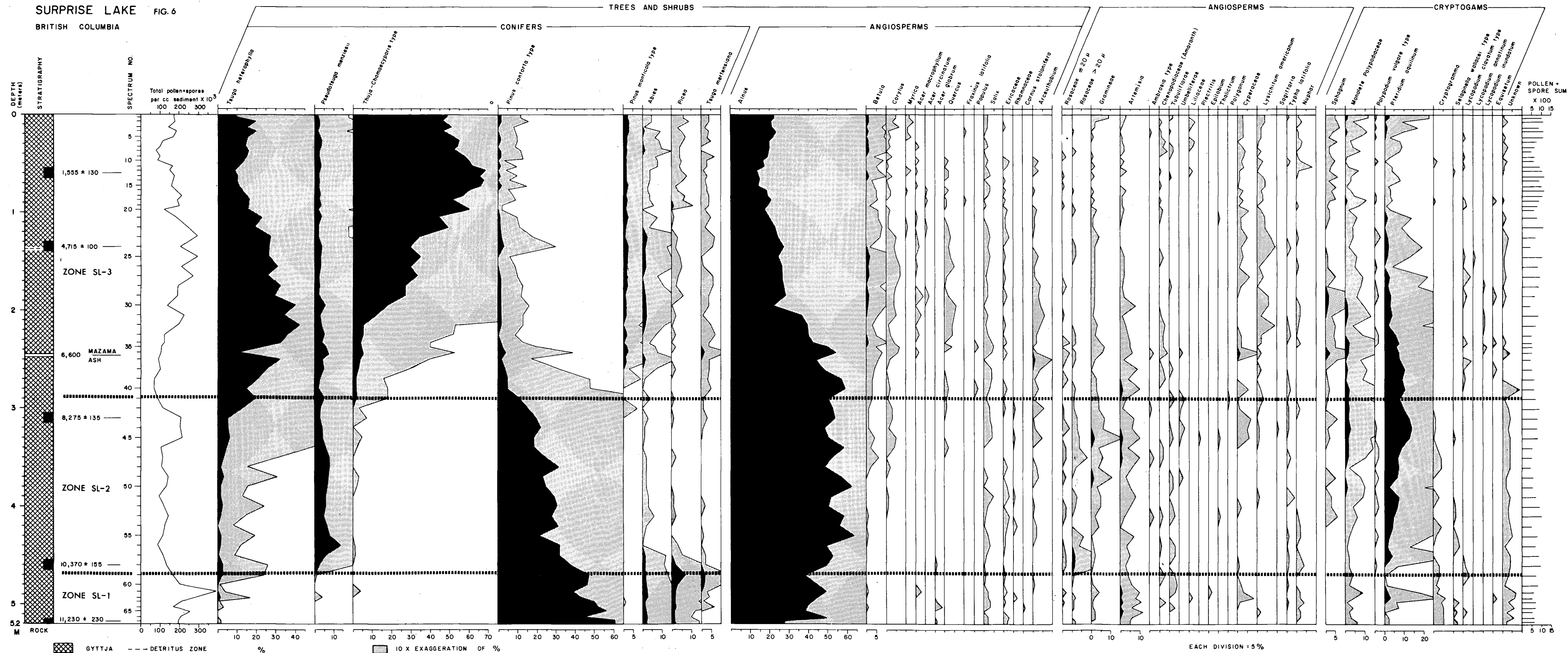
Plantago lanceolata L.

CAPRIFOLIACEAE

Linnaea borealis L.



SURPRISE LAKE FIG. 6
BRITISH COLUMBIA



PINECREST LAKE, BRITISH COLUMBIA

ROLF MATHEWES

Fig. 10

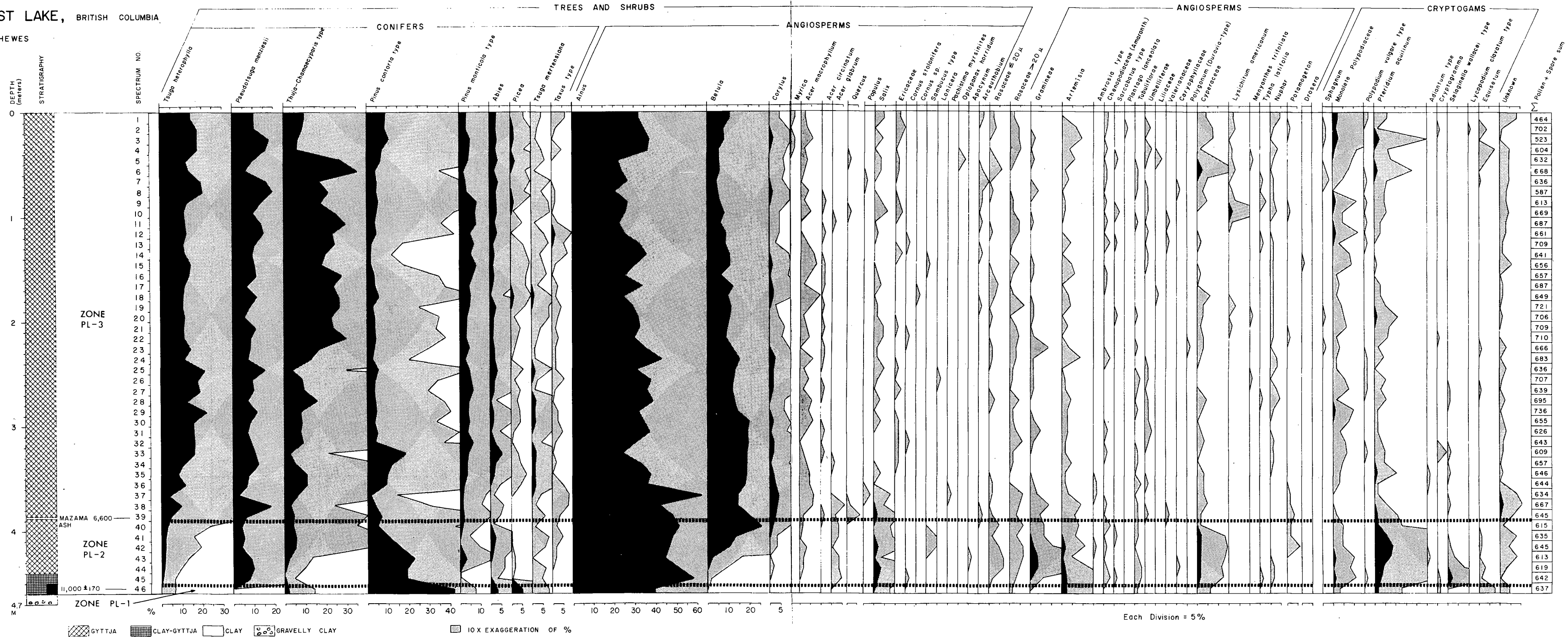


Fig. 11

