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PALYNOLOGICAL AND MACROFOSSIL ANALYSES OF LAKE SEDIMENTS FROM THE LILLOOET AREA, BRITISH COLUMBIA

by

Miriam King

B.Sc.(Hons.), University of Toronto, 1974

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APPROVAL

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Date approved December 17, 1980.

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Title of Thesis/~~Project/Extended Essay~~

Palynological and macrofossil analyses of lake sediments from the Lillooet area, British Columbia

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Dec 17/80

(date)

ABSTRACT

Sediment cores providing a stratigraphic record of approximately the last 7750 radiocarbon years BP were taken from two small lakes near Lillooet, British Columbia. These lakes are located near the boundary between Interior Douglas Fir and Ponderosa Pine-Bunchgrass biogeoclimatic zones, and it was hoped that the sediments would contain a record of any climatic shifts occuring within this climatically transitional area.

Pollen, spores, and plant and mollusc macrofossils were examined for such a record, and used to reconstruct local as well as regional changes in the environment. In particular, attention was paid to those conditions which might represent a period of maximum warmth/drought during the postglacial, and those which might have some impact upon prehistoric native peoples, in relation to the Lillooet Archaeological project.

Diagrams were constructed of pollen influx and relative frequency values, and of the raw macrofossil counts. The diagrams were zoned into "biostratigraphic" units on the basis of visual examination. Two pollen zones were recognized in Phair Lake and three in Chilhil Lake, the larger and older of the two. The lowermost pollen zones (CL-1 and PHL-1) both could be interpreted as indicating drier conditions, which terminated about the time of Mazama volcanic ash deposition.

In Phair Lake, these drier conditions ceased circa 6200 radiocarbon years BP, and the pollen record indicates stable, moister conditions above this level. In Chilhil Lake, conditions

have become moister since about 7000 radiocarbon years BP, with drought conditions reappearing between circa 6100 and 6300 years BP.

The dating of these changes is made possible by both radiocarbon samples and ash layers. Three radiocarbon dates and two ash layers, identified as Bridge River and Mazama tephras, date the Phair Lake sediments, while two valid radiocarbon dates and one ash layer (Mazama) date the Chilhil core.

The macrofossil diagrams were zoned independently of the pollen diagrams, but there is some correspondence between macrofossil zone boundaries and the major pollen zone boundaries. The macrofossil data, however, were in general less complacent than the pollen data, and provided additional information for the interpretation of local environmental conditions.

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Finally, thanks are due to Ron Long of the S.F.U. Biology Department and Ray Squirrel of the Geography Department for their excellent photographic work, and to Mike Kennedy and the Native peoples of the Lillooet area for allowing access to the lakes under study.

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INTRODUCTION

Two permanent lakes were selected for pollen analysis near the boundary between Krajina's (1969) Interior Douglas Fir and Ponderosa Pine-Bunchgrass biogeoclimatic zones, in the vicinity of Lillooet, British Columbia. This area was selected for two reasons. Firstly, it was felt that this type of transitional area would exhibit greater sensitivity to any postglacial changes in climate which might affect the vegetation. Such changes, if present, were apparently largely masked at sites further south and west down the Fraser Valley where more coastal conditions prevail (Mathewes 1973; Mathewes and Rouse 1975). Secondly, it is within the study area of the Lillooet Archaeological Project, directed by Dr. Arnoud Stryd. It was hoped that paleoenvironmental data from these lakes would contribute to an understanding of the archaeological record of human occupation of this area.

Thus the purposes of this study are several: to provide a reconstruction of the postglacial vegetation of the Lillooet area, to determine if a period of maximum warmth/drought (i.e., a Xerothermic or Hypsithermal) occured in this presumably sensitive area, to look for evidence of other Holocene climatic changes and finally, to relate, if possible, this information to known settlement patterns of the prehistoric peoples inhabiting this area. To these ends, palynological studies, supplemented by macrofossil analysis of both plant and mollusc remains, and some analyses of sediments, were carried out. The results from the two lakes were compared both to each other and to other sites within British Columbia.

It was hoped that at least one of the cores examined would provide a complete record of the postglacial sequence, a period of about 10,000 to 11,000 years (Ryder 1978). However, radiocarbon dating of the basal sediments indicates that both lakes were formed at some time subsequent to the wasting and withdrawal of the main body of ice. The relatively recent basal dates are undoubtedly a function of the geography and nature of the genesis of the two lakes.

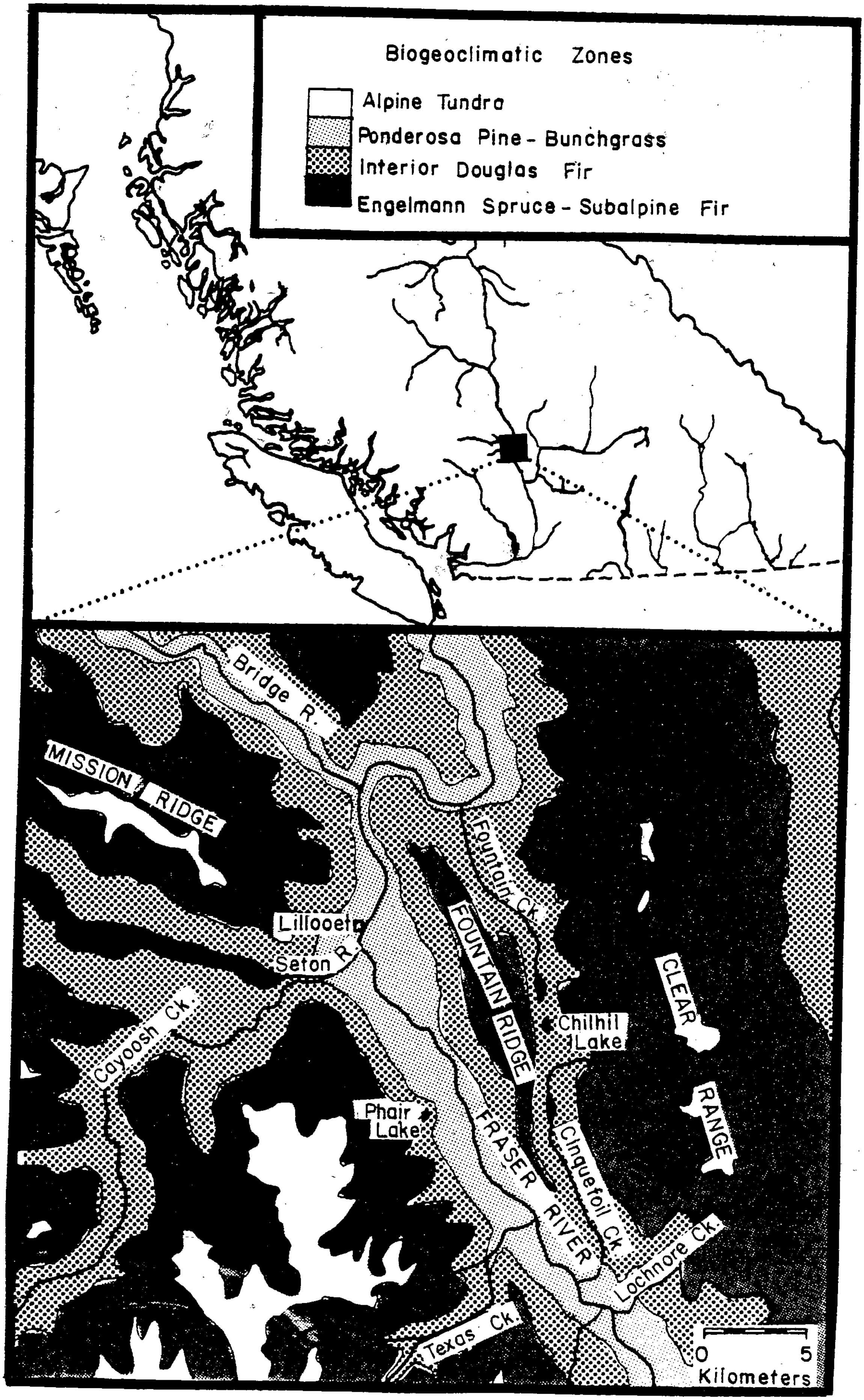
1. THE STUDY AREA

1.1 Description of the Sites

The lakes selected were Phair Lake and Chilhil Lake near Lillooet, in the Interior Plateau region of British Columbia (see Fig. 1). The lakes are only 7.1 kilometers apart, but are separated by the Fraser Canyon and Fountain Ridge. Other differences in setting which may contribute to differences in the nature of the depositional records of the two lakes are described below.

Phair Lake (50° 36' 30" N, 121° 52' 40" W; Fig. 2) is located on the west side of the Fraser Canyon, about 8 kilometers south of the town of Lillooet. It is situated at the base of the Coast Mountains at an elevation of about 705 meters, on one of the complex benches of glacial till, glaciofluvial material and colluvium that line the Fraser River. The bench slopes fairly gradually to the east, with steeper slopes found to the north and west. The northern slope is in part an unvegetated talus slope, rising to a maximum elevation of about 884 meters. Here the bedrock is exposed, a complex of Triassic or pre-Triassic slate or chert (Duffel and McTaggart 1952). To the west is the main bulk of the Coast Range, with Mt. Brew rising to a height of approximately 2,320 meters. According to Duffel and McTaggart (1952), the bedrock of this slope consists largely of lower Cretaceous granodiorites, and there is a fault line just to the east of the lake separating the materials of the Coast Mountains from the argillites,

Fig. 1 Map of the study area, illustrating Biogeoclimatic zones, adapted from Mathewes (1978).


Biogeoclimatic Zones
Alpine Tundra
Ponderosa Pine - Bunchgrass
Interior Douglas Fir
Engelmann Spruce - Subalpine Fir
Bridge R.
MISSION RIDGE
Fountain Ck.
FOUNTAIN RIDGE
CLEAR RANGE
Lillooet
Seton R.
Cayoosh Ck.
Chilhil Lake
Phair Lake
FRASER RIVER
Cinquefoil Ck.
Lochnore Ck.
Texas Ck.
0 5
Kilometers

volcanic conglomerates and tuffaceous sandstones of the Lillooet group.

Topographic maps indicate a permanent outlet from Phair Lake, but no inlet stream. In fact, there is a small creek which enters the lake from the west, which may be meltwater from a higher elevation glacier or seepage from a spring. It was not possible to trace the creek to any great height above the lake. The outlet channel is clearly visible, but at present contains no water and is overgrown with vegetation. This channel appears to have been purposely blocked with earth, perhaps to facilitate cattle grazing around the lake. The lake itself is small (about 210 m by 275 m) and has one relatively deep basin near its centre, which reaches a depth of about 4.9 m.

Chilhil Lake lies farther to the east and north (50° 39' N, 121° 47' 58" W; Fig. 3), in the Fountain or Three Lakes Valley which lies between Fountain Ridge and the Clear Range. This valley runs almost due northwest-southeast for about 19.2 km, the product of two fault lines. It debouches at either end into the Fraser Canyon.

Of the three lakes found in the valley, Chilhil is central and actually lies at the highest point on the valley floor, an elevation of slightly less than 915 m. Kwotlenemo Lake lies to the north and is drained by the northward flowing Fountain Creek. Cinquefoil Lake lies to the south and is drained by the southward flowing Cinquefoil Creek. Chilhil itself, the smallest of the three lakes, lies within a topographic depression, suggesting that it is a kettle lake. There

Fig. 2 Photograph of Phair Lake showing surrounding forest. The core is being taken from the anchored boat.

Fig. 3 Photograph of Chilhil Lake, looking westward from sparsely treed pasture to relatively undisturbed forest on the other side of the lake.

are no apparent input or output channels surrounding Chilhil, either marked on the topographic map or evident in the field, and there is no clear sign of any past interconnections between the lakes. These field observations contradict Ryder (1976), who identifies an inlet stream flowing into the north end of Chilhil Lake.

While Chilhil is a fairly small lake (about 760 m by 305 m), it should be noted that it is much larger than Phair Lake, with a surface area of about 2.3 hectares as compared with 0.5 hectares. It is also more uniform in depth and somewhat shallower - random depth soundings indicated a maximum depth of only 4.1 m.

The mountain ranges which border the valley are the dissected remnants of the Interior Plateau, and rise to similar elevations of about 1800 m, though the more extensive Clear Range includes some higher peaks. Fountain Ridge consists of Cretaceous rocks of the Jackass Mountain Group, composed mostly of greywacke, argillite and conglomerates, and faulted sandstones (Duffel and McTaggart 1952). The Clear Range consists of the Spences Bridge Group, of similar material plus some volcanic rock (Ryder 1978). Glacial till mantles the valley itself, with what Ryder (1976) calls "mudflow" covering the valley floor.

1.2 Glacial History

Both sites were glaciated. During the last glaciation, accumulation occured primarily in the Coast Mountains, and the ice generally flowed eastward, transverse to the valleys (Ryder 1976).

The date of deglaciation is in question. Ryder (1978, p. 63) states that "......no absolute dates related to deglaciation have been determined from within the Lillooet area". Basal peat from a bog at Jesmond, 55 km north of Lillooet, has been dated at 9210 ± 150 radiocarbon years BP (Before Present), while mudflows within an alluvial fan at Lochnore Creek, 18 km south of Lillooet have been dated at 11,285 ± 1000 years BP (Ibid). Thus at least portions of the study area may have been ice free by 11,000 radiocarbon years BP.

Wasting of ice occured first on the crests of the ranges, while massive tongues of ice remained in the main valleys, Eventually this ice melted as well, leaving only isolated ice blocks in outwash and morainic material. Chilhil is most likely a kettle lake, which formed as a result of ice-melt subsequent to general deglaciation of the surrounding area. The origin of Phair Lake is unclear. Its shape is not suggestive of a kettle lake but would seem to indicate the presence of a fault line, or formation as a result of a rotational slump.

Ryder (1978) reports several neoglacials in the mountains around Lillooet, involving postglacial expansion of high-elevation glaciers, between 5800 to 4900 years BP, 3300 to 2300 years BP, and 1000 to 0 years BP.

1.3 Biogeoclimatic Zones

Both lakes are found within the Interior Douglas Fir biogeoclimatic zone of Krajina (1969). Chilhil, located some 200 m or so higher in elevation, represents the wet subzone of that zone. Thus, while the transition to Ponderosa Pine-Bunchgrass zone is located only a few hundred meters to the east of Phair Lake, the nearest true expression of this drier zone near Chilhil is found at the north and south ends of the Fountain Valley, along the Fraser River.

At higher elevations immediately west of Phair Lake, and to both the west and east of Chilhil, is Engelmann Spruce-Subalpine Fir zone vegetation. Farther to the west, species characteristic of Mountain Hemlock and Coastal Western Hemlock zones appear. There is also some Alpine Tundra in the Coast Mountains and to the east in the Clear Range (Fig. 1).

This zonation is significant as regards regional pollen rain, since Phair Lake would seem to lie in the path of the prevailing westerlies. Thus winds would carry pollen from the high-elevation biogeoclimatic zones as well as the surrounding Interior Douglas Fir zone.

Chilhil also seems to lie in the path of the westerlies, but during the time spent at the site, winds appeared to follow the length of the valley, blowing from the south. Of the two lakes, Chilhil might therefore be more likely to receive a pollen rain containing palynomorphs characteristic of the lower elevation Ponderosa Pine-Bunchgrass zone, which would form a significant proportion of the Phair Lake influx only if the zone boundary were to shift upslope.

No climatic data were quantitatively measured at either site. Instead, information as to general climatic conditions were taken from Krajina (1969; see Table 1).

1.4 Vegetation

The vegetation of the sites was examined on two occasions, and identified following the nomenclature of Taylor and MacBryde (1977). The natural cover around both lakes is somewhat disturbed by road cuts and pastureland, and both sites are presently used for cattle grazing. A number of introduced species are present on disturbed ground at both sites.

Species found at Phair Lake are typical of the Interior Douglas Fir zone, including both climax and riparian communities. The dominant upland tree species surrounding most of the lake is *Pseudotsuga menziesii* var. *glauca* (for common names, see Appendix I), with occasional *Pinus ponderosa* in the vicinity.

Other tree species found encircling the lake are *Populus tremuloides*, which forms a stand on the south-facing slope lying to the north of the lake, *Betula papyrifera*, *B. occidentalis*, *Acer glabrum* var. *douglasii*, *Alnus incana*, and *Salix* spp. The birches and maple are most abundant on the flat, low delta area formed by the input stream. The alders and willows are confined largely to the lake's edge. One large *Thuja plicata* was found in the small ravine incised by the input stream.

Shrub species noted around the lake are *Juniperus scopulorum*, *J. communis*, *Amelanchier alnifolia*, *Cornus sericea*

TABLE 1

CLIMATIC CONDITIONS IN THREE BIOGEOCLIMATIC ZONES,

KRAJINA (1969)

	Ponderosa Pine-Bunchgrass	Interior Douglas Fir	Engelmann Spruce-Subalpine Fir
Elevation	270 - 600 m	600 - 1200 m	1200 - 1800 m
Mean Annual Temp.	6 to 10°C	4 to 9°C	1 to 4°C
January Mean Temp.	-8 to -3°C	-12 to -3°C	-18 to -7°C
July Mean Temp.	18 to 22°C	17 to 21°C	12 to 16°C
Absolute Max. Temp.	38 to 44°C	36 to 43°C	32 to 37°C
Absolute Min. Temp.	-41 to -21°C	-46 to -32°C	-56 to -34.5°C
No. Frost-free Days	100 to 200	75 to 200	50 to 100
Mean Annual Precip.	19 to 36 cm	36 to 56 cm.	41 to 183 cm.
Driest Month Precip.	0.7 to 1.5 cm.	1.3 to 2.8 cm.	1.5 to 6.6 cm.
Wettest Month Precip.	2.9 to 5.1 cm.	5.1 to 8.9 cm.	6.4 to 25.4 cm.
Annual Snowfall	50 to 152 cm.	76 to 178 cm.	175 to 1016 cm.
Snowfall as % of Total	19 to 42	21 to 35	43 to 72

and Crataegus douglasii (both of which are riparian species), Mahonia aquifolium (a wet subzone species) Prunus virginiana, Ribes divaricatum, R. irriguum, R. lacustre, Rosa acicularis, R. nutkana, Rubus parviflorus, Sambucus racemosa, Shepherdia canadensis, Spiraea betulifolia, Philadelphus lewisii, plus the disturbed ground species Rubus idaeus, R. leucodermis and Symphoricarpos alba. Confined to the marshy area of the inlet are Oplopanax horridus and Ribes viscosissimum, both riparian species.

Herbaceous species found include Actaea rubra, Allium cernuum, Aquilegia formosa, Aralia nudicaulis, Arnica cordifolia, Aster conspicuus, Astragalus miser, Carex spp., Clematis occidentalis, Corrallorhiza striata, Cypripedium sp., Disporum trachycarpum, Equisetum arvensis, E. hyemale, Fragaria virginiana, Goodyera oblongifolia, Galium sp., Poa sp., Pyrola virens, Smilacina racemosa, Solanum americanum, Streptopus amplexicalus, Urtica dioica, and Viola adunca.

Very disturbed ground also supported the following species; Achillea millefolium, Bromus tectorum, Capsella bursa-pastoris, Cirsium sp., Epilobium angustifolium, Fragaria virginiana subsp. glauca, Plantago major, Poa pratensis, Potentilla sp., Stellaria longipes, Taraxacum officinale, Tragopogon sp., Trifolium repens, and Viola sp.

Species found only on the talus slope include Artemisia frigida, A. cf ludoviciana, Heuchera cylindrica, Penstemon fruticosus var. scouleri, Phacelia hastata, and the fern Woodsia.

Emergents and aquatics include Carex rostrata, C. aquatilis, *Chara* sp., *Potamogeton* sp. and *Sparganium* sp.

The area around Chilhil Lake is much more disturbed, with open pasture to the south, and treed pasture to the east and north (Fig. 3). Relatively undisturbed forest is found on the west bank of the lake, as well as at higher elevations in the Fountain Ridge and Clear Range.

Tree species found include *Pseudotsuga menziesii* var. *glauca*, *Populus tremuloides* (particularly in the treed pastures), and *Acer glabrum* var. *douglasii*. Some *Betula papyrifera* was present at the southwest end of the lake, but all the individuals were dead. Shrubs found include *Juniperus communis* (a key species in the treed pasture), *J. scopulorum*, *Amelanchier alnifolia*, *Mahonia aquifolium* and *Paxistima myrsinites* (2 spp. of the wet subzone), *Prunus virginiana*, *Ribes lacustre*, *Ribes* spp., *Rosa* sp., *Rubus idaeus*, *Shepherdia canadensis*, *Spiraea betulifolia* and *Symphoricarpos alba*. Also in the vicinity, though not immediately around the lake are *Ceanothus velutinus*, *C. sanguineus*, and *Vaccinium* sp. (blueberry).

Herbaceous species include *Achillea millefolium*, *Agropyron spicatum*, *Allium cernuum*, *A. validum*, *Allium* sp., *Anemone multifida*, *Aquilegia* sp., *Arabis holboellii*, *Arabis* sp., *Arctostaphylos uva-ursi*, *Astragalus miser* var. *serotinus*, *Astragalus* sp., *Bromus tectorum*, *Buglossoides arvensis*, *Carex concinnoides*, *Carex* spp., Caryophyllaceae, *Cerastium vulgatum*, *Cirsium* cf *edule*, *Corydalis aurea*, *Delphinium nuttallianum*, *Descurainia pinnata*, *D. richardsonii*, *Disporum trachycarpum*, *Festuca* sp., *Fragaria virginiana*, *Heuchera cylindrica*, *Hieracium* sp., *Lathyrus ochroleucus*, *Linnaea borealis* (a wet subzone species), Lithosperum ruderale, Medicago sp., Orithilia secunda, Poa pratensis, Poa sp., Polemonium pulcherrimum, Potentilla anserina, P. cf nivea, Ranunculus glaberrimus var. ellipticus, Sedum lanceolatum, Sonchus sp., Streptopus amplexifolius, Taraxacum officinale, Trifolium sp., Viola canadensis, V. adunca, Urtica dioica and Woodsia sp.

On the mudflats at the lake's edge were found Chenopodium capitatus, Polygonum sp., and Ranunculus cf sceleratus. Submerged or emergent aquatic vegetation included Chara sp., and species of Potamogeton and Myriophyllum.

Also found in the Fountain Valley are occasional Pinus ponderosa, particularly at the south and north ends of the valley (the closest appears to be about 2.6 km from the north end of the lake). Pinus contorta is found in a dense stand about one-third of a kilometer from the south end of the lake. Going farther south towards the Fraser River are some cleared areas supporting grasses and Artemisia species.

At higher elevations, the occasional Abies and Picea were visible.

2. METHODS

2.1 Field Methods

Two trips were made to the lakes under study, the first in June of 1976 and the second in May of 1977, to retrieve lake sediments for analysis and to carry out a qualitative survey of the vegetation. Both lakes were sampled from anchored boats using a hand-operated 5 cm diameter Livingstone piston corer, with a 7 cm diameter casing to maintain the integrity of the bore hole. The loose upper sediments were sampled using a Brown corer with a clear plastic sampling tube.

An attempt was made to retrieve sediments from the deepest portion of both lakes as determined by sounding with a disc and chain, in order to secure the longest continuous records of sedimentation. In Phair Lake, a small, relatively deep basin (4.5 to 4.9 m of water) near the centre of the lake was sampled. On the first trip, 285 cm of material including 50 cm of Brown core were retrieved, before coring was halted by a layer of compacted woody peat. On a second trip, the basal portion was retrieved from the same locality, resulting in a total core length of 374 cm.

Sampling at Chilhil Lake may not have occured in the deepest part of the lake, but soundings failed to indicate any portion of the lake much greater than 4 meters in depth. The sediments were removed from 4.1 meters of water near the centre of the lake and consisted of approximately 50 cm of Brown core and another 360 cm of material retrieved with the Livingstone sampler. On closer examination, it was found that the upper portion of the first section from the Livingston sampler represented contamination, and after analysis (which confirmed the contamination), the upper 20 cm of material was discarded (see Fig. 4). Thus the final length of this core was 390 cm, not 410 cm.

Brown cores were stored in their plastic tubes in an upright position to prevent mixing. The other sediments were extruded from the Livingstone corer, wrapped in aluminum foil, and labeled. All materials were transported to Simon Fraser University and stored at 4 degrees Celsius until analysed.

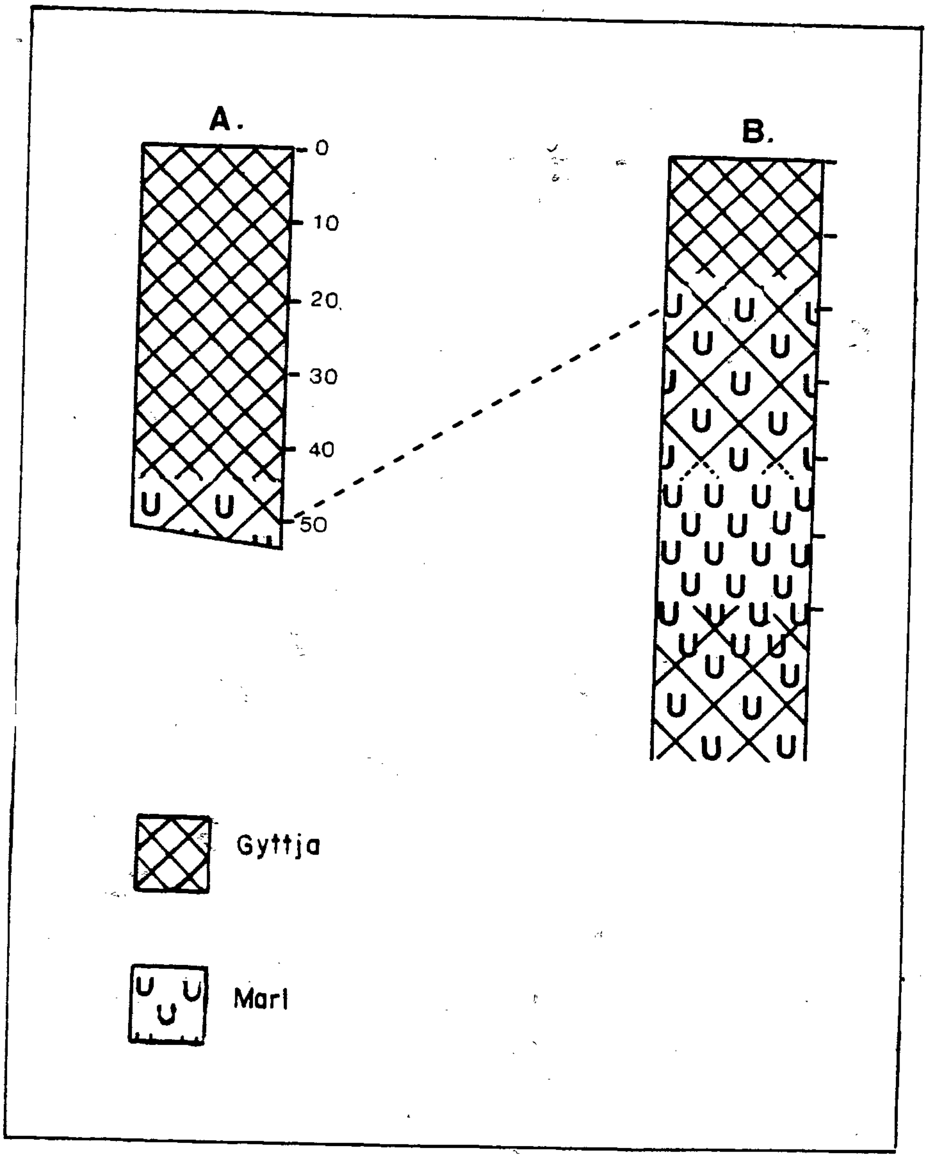
A third field session was undertaken in September of 1978, primarily to expand the vegetation survey. Unfortunately, due to time constraints, this trip provided little quantitative data to add to the species lists prepared during the first two trips (see Section 1.4 and Appendix I). Soil surface samples for pollen analysis were, however, collected from the vicinity of both Phair Lake and Chilhil Lake. These samples consisted of the upper centimeter of soil or a moss polster. More detailed analyses of vegetation (i.e., percent cover) were made for the 1 m by 1 m quadrats from which the samples were taken at Phair Lake.

2.2 Sample Preparation

Pollen Samples

In the laboratory, 1 cc plugs of material were taken from the cores at 5 cm intervals for pollen analysis. The surfaces of the cores were first scraped to remove contamination that may

Fig. 4 Stratigraphic comparison of sediments from the Brown core (A) with those from the upper portion of the first section of Livingston core (B), Chilhil Lake.


A.
B.
0
10
20
30
40
50
Gyttja
Marl

have occured when the core segments were extruded from the tubing in the field. These subsamples were stored in labeled and sealed glass vials and refrigerated until processed. Dry weights were not determined.

Samples were processed using a modification of the methods of Faegri and Iversen (1975). Treatment involved using hot 6% KOH, 10% HCl, 52% HF, followed by acetolysis solution (9 parts acetic anhydride to 1 part sulfuric acid). The samples were then dispersed in ethanol, followed by Tertiary Butyl Alcohol, and stored in silicon oil. Processing of clay-rich samples entailed an additional step. Due to the slow action of the HF and the problem of silico-fluoride precipitation, a modification of the method described by Cwynar et al (1979) was used. Warm 5% Sodium Pyrophosphate was added following treatment in KOH and HCl to deflocculate the clays and thereby increase the effectiveness of the subsequent HF treatment. The sediments were resuspended in $Na_4P_2O_7$ following acetolysis and passed through a 7 micron mesh screen, using gravity filtration. This produced relatively silicate-free samples in most cases.

Soil surface samples were similarly processed, but a larger amount of material was used (10 to 20 cc), and screened carefully through a 250 micron mesh sieve subsequent to treatment in KOH. Moss polsters were processed using acetolysis only, unless they contained a great deal of sediment, in which case HF was used.

To allow determination of pollen concentrations and influx values, and to gauge the effects of processing on preservation, two prepared tablets of Eucalyptus pollen were added to each subsample before processing. One tablet (as prepared by Jens Stockmarr, batch No. 903722) contained approximately 16,180 $\pm$ 1460 pollen grains in a matrix of calcium carbonate, soluble in HCl.

Slides for microscopy were prepared using a drop or two of the final sediment-silicon oil suspension, mounted under a No. "0" coverslip. Palynomorph counting was done at 400 times magnification using a Zeiss microscope, while difficult identifications necessitated using immersion oil and a magnification of 900 times.

The remainder of both cores was rewrapped and replaced in a refrigerated room until further samples were required. This included resampling for those levels which, for one reason or another, had to be reprocessed, as well as materials for radiocarbon dating, macrofossil analysis, and sediment analysis.

Sediment Analyses

The analysis of sediments was limited, although an attempt was made to follow the classification system of Troels-Smith (1955) as modified by the International Geological Correlation Program (Berglund 1979). The sediments were classified largely on the basis of appearance (e.g., colour) and elasticity. Also, 2 cc subsamples were taken at 10 cm intervals, except in the Brown core, and those segments used for radiocarbon dating. These were used to determine dry weights, loss on ignition values, and ash weights.

Wet weights were first measured, and then the materials were dried at temperatures of between 105 degrees and 110 degrees Celsius for twenty-four hours. Because the cores were stored for a considerable length of time before these subsamples were taken and processed, dehydration may have occured in parts of the cores, and thus estimates of water content may be unreliable.

Loss on ignition was determined by burning the samples (transferred to porcelain crucibles) in a muffle furnance at 350 degrees to 400 degrees Celsius for eight hours, as recommended by Hesse (1971). Many of the samples came from calcareous sediments (mostly marl), and thus the loss on ignition figures should be considered as only general indicators of the presence of organic matter.

Ashing to determine inorganic carbon contents was also carried out in a muffle furnace at temperatures of 800 degrees to 850 degrees Celsius for three hours. A thirty minute burn was attempted for some Chilhil Lake samples, but combustion was generally found to be incomplete.

The ash weights derived have not been corrected to account for the 5% to 10% of organic carbon not combusted at the low temperatures used for the loss on ignition tests (Hesse 1971), or the structural water released from clays and estimated as the equivalent of 5% of the weight of the clay in the sample (Bear 1964). It was simply noted that there is actually less inorganic carbon and more organic carbon than measured, especially where L.O.I. values are high, and that inorganic carbon estimates for clay-rich sediments should be lower.

Macrofossil Analysis

The last samples to be taken were those for macrofossil analysis, since this involved slicing the remainder of the core into 5 cm long chunks. The possibly contaminated exterior of these segments was carefully scraped, and then these samples were wet sieved, using detergent as a deflocculent, through a 500 micron mesh screen. The residual sediment greater than 500 microns was retained for analysis.

Samples were selected at 10 cm intervals, and all seeds, molluscs, plant and wood fragments were removed for identification and counting using a Wild stereomicroscope. These materials were then stored in glass vials in a mixture of alcohol and water to prevent fungal and bacterial growth. The presence of other macrofossils, such as *Daphnia* ephippia, ostracods, and fungal spores was noted but these were not saved, nor are they discussed in this thesis.

2.3 Identification

Pollen and Spores

A total of 400 grains was initially counted per level; this count was subsequently raised to 450. It was considered unnecessary to further increase the count to 500 grains, since there is little or no difference in the 95% confidence intervals for 450 and 500 grains (Maher 1972). Traverses were spaced so that no matter what the concentration, some pollen was counted near the edge of the coverslip, as well as in the centre of the slide, to compensate for any drift of the small grains towards the edges.

Palynomorphs were identified using the keys given in Faegri and Iversen (1975) and Kapp (1969), as well as reference material from British Columbia. In most cases identification is to the genus level only; in some cases, to family. For example, Thuja and Juniperus are both present at Phair Lake, but since it was not deemed possible to separate their pollen with any certainty, these palynomorphs were classified only as "Cupressaceae". At Chilhil Lake, only Juniperus species are present, and all Cupressaceae could be attributed to that genus.

Identification to species level is occasionally possible, particularly where a genus is represented by a single species within the study area. In some cases "cf" or "Type" designations were used. Botanical nomenclature throughout this paper follows that given by Taylor and MacBryde (1977).

An attempt was made to separate the pollen of pine species. Diploxylon and Haploxylon pines were separated using the criteria given by Hansen and Cushing (1973). These authors note that subgenus Haploxylon pine grains have "verrucae or scabrae on the furrow membranes in an areolate or semi-areolate pattern", while those of subgenus Diploxylon have a membrane which is psilate or has only scattered scabrae (Ibid., p. 1183). They also note that the latter have a sharper transition between the cap and furrow membrane. Other characteristics also differ, but the above two were most consistently useful in identification.

Haploxylon pine pollen is referred to as _Pinus monticola_ type on the pollen diagram, but probably represents _Pinus albicaulis_ which occurs at subalpine elevations in this area (Mathewes 1978). The subgenus Diploxylon includes both _Pinus contorta_ and _P. ponderosa_. Due to the ecological significance of _Pinus ponderosa_ as a species of the drier ecotones, an attempt was made to distinguish between these two species.

The state of preservation of most grains, their large number, and their positioning on the slide made it difficult to use qualitative differences noted by Hansen and Cushing (1973, pp. 1186-7), such as the shape of the bladder (spherical in _ponderosa_, hemispherical in _contorta_), the length of intersection of bladder and furrow membrane (short in _ponderosa_, long in _contorta_), and presence of a marginal frill. Instead, it was decided to attempt to separate the grains on the basis of size, looking at total length, corpus breadth and a measure of bladder length (see Fig. 5). Alley (1976, p. 1138) notes that "grains of P. ponderosa are consistently larger than those of P. contorta", and that the bladders of the former tend to be greater than half of the central body in size, while those of the latter are less than half.

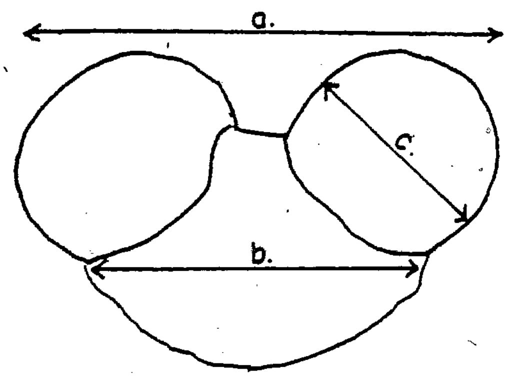


Fig. 5 - Dimensions measured on Pine pollen grains.

Reference material from British Columbia was examined to determine if there was indeed a consistent difference in size between the species. One hundred grains were examined from each of two slides of Pinus contorta (representing populations from Cassiar and Aspen Grove) and two of P. ponderosa (representing populations from Princeton and Mahoney Lake).

These measurements indicated that while total length and corpus length were highly variable, having a great range within each sample, bladder length was less variable. Difference of means tests indicate that the differences in bladder lengths between the two populations of Pinus contorta, and between the populations of P. contorta and P. ponderosa are significant at the 99% confidence interval. The two populations of

Pinus ponderosa were sufficiently alike that there was no significant difference in means at either the 99% or 95% confidence interval.

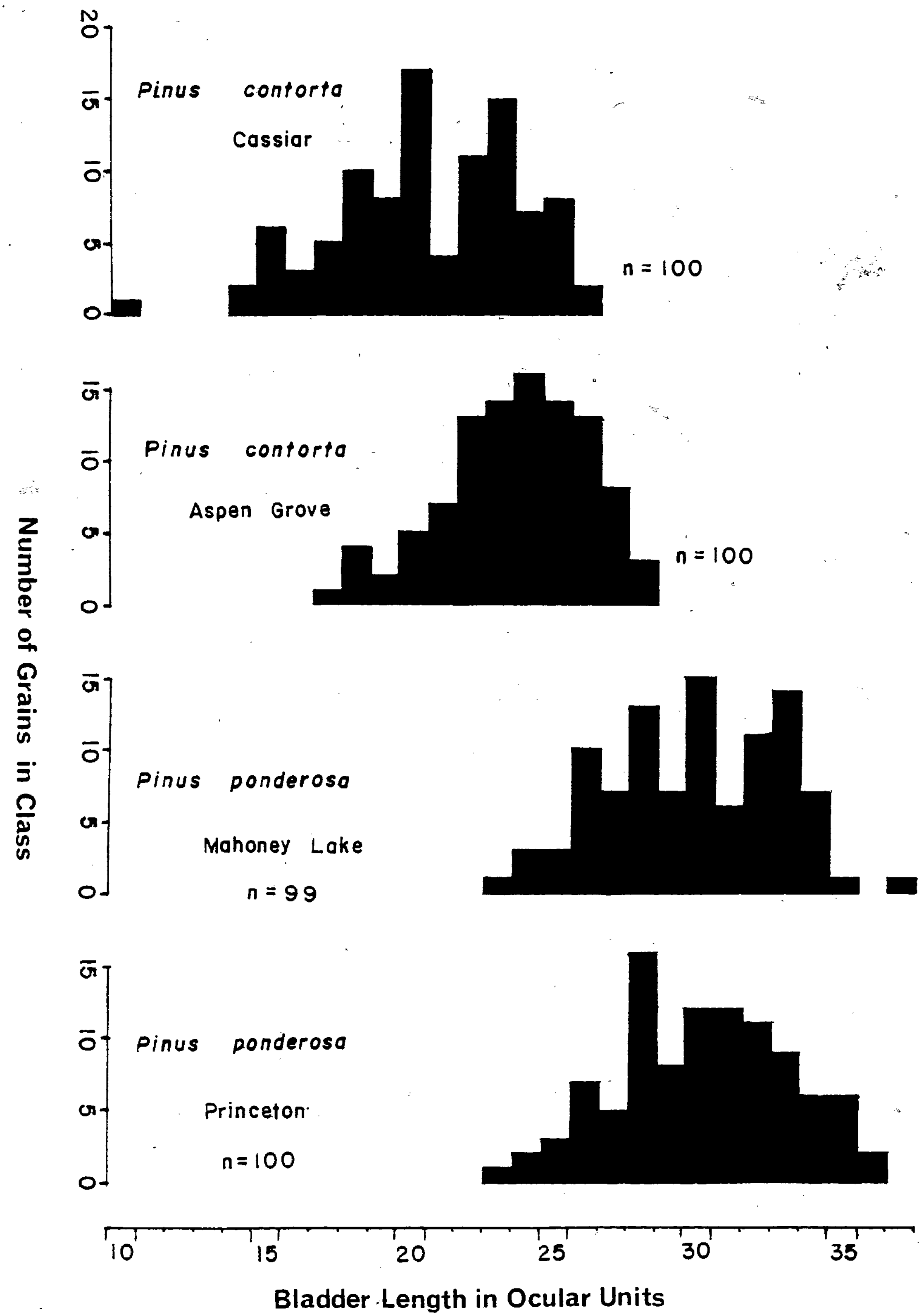
However, there is still sufficient overlap between bladder lengths of the two species as to make their separation somewhat arbitrary (see Fig. 6). Probability suggests that for the reference material used, the dividing line is 26 to 27 ocular units (or 31 to 32.4 microns; ocular units being used as a unit of measurement to facilitate the consideration of large numbers of pollen grains), with _Pinus ponderosa_ bladders exceeding that length.

The fossil material was then examined, and between 25 and 30 whole pine grains were measured as to bladder length, in hopes of producing a ratio of _Pinus contorta_ to _P. ponderosa_ which could then be extrapolated to the rest of the Diploxylon grains found at a level. This was eventually abandoned, as the arbitrary nature of the division into the two species on the basis of bladder length became apparent. Histograms of the bladder sizes measured per level indicated no bimodality, but approximated a normal distribution. This, coupled with the fact that the reference material used to set up the size classes did not come from the study area, nor were there reference slides of _P. ponderosa_ and _P. contorta_ from the same site, caused the author to abandon the attempt to separate the two species.

It might be noted that Mack (1971), who looked at corpus breadth in a large number of reference slides from a variety of locales, found that "neither range nor standard

Fig. 6 Bladder lengths of *Pinus contorta* and *Pinus ponderosa*, based on counts of 100 pollen grains per slide.

One ocular unit equals approximately 1.2 microns.


Pinus contorta
Cassiar
n = 100
Pinus contorta
Aspen Grove
n = 100
Pinus ponderosa
Mahoney Lake
n = 99
Pinus ponderosa
Princeton
n = 100
Number of Grains in Class
Bladder Length in Ocular Units
0
5
10
15
20
10
15
20
25
30
35

deviation of corpus breadth can be used to separate these species " (p. 265). He found bimodal and even trimodal size curves for a single species, and great variations in size within a species over as small a distance as 75 kilometers (Ibid).

Besides this natural variation within and between populations, one might also consider that some of the grains measured were deformed or altered by the processing, which may not have been the same as that for the reference material (data on processing were not available for all reference slides). There might also have been differential breakage between the two species, which would be significant since only whole pine grains were measured.

Macrofossils

Plant macrofossil remains were identified as far as possible using a number of reference texts, including Montgomery (1977), Martin and Barkley (1961), Katz, Katz, and Kipiani (1965). Comparison with reference material collected in the field or taken from the University of British Columbia Herbarium was made whenever possible. Photographs of selected plant macrofossils are shown in Plate 1.

Molluscs provided a somewhat greater difficulty, since reference material was not available. Reference works most used were Ward and Whipple (1959), and the extended paper by Clarke (1973). Nomenclature of molluscs within this paper follows Clarke (Ibid).

Molluscs found belonged to either the class Pelecypoda (the bivalves, referring to the 2-valved calcareous shell within which they are enclosed) or the class Gastropoda (the univalves). All Pelecypoda found belonged to the super-family Sphaeriacea, the pill clams, and to the genera *Sphaerium* or *Pisidium*. These two genera were not separated, since this would have involved a more detailed examination of the specimens than time allowed.

Gastropoda found belonged to two subclasses, the Prosobranchs (gill-breathers) and the Pulmonata (lung breathers). Identification was to genus and occasionally to species. Pulmonates include the species *Physa jennessi skinneri* and indeterminable *Physa* sp., *Promenetus*, *Gyraulus deflectus* (see Plate 2a), *Helisoma* cf *corpulentum* (Plate 2b), *H.*, *trivolvis* (Plate 2e) and other undifferentiated *Helisoma* spp., and Lymneids (of *Lymnaea* spp., Plate 2d). Prosobranchs include *Amnicola* (from Chilhil Lake only) and *Valvata sincera heliocoidea* (Plate 2c).

2.4 Radiocarbon Dates and Ash Layers

A total of four samples were taken from Chilhil sediments for radiocarbon analysis. A basal segment (380 to 390 cm) sent to Teledyne Isotopes yielded an anomalous date of 4860 $\pm$ 130 years BP (I-10,044) though it falls about 80 centimeters below the diffuse ash layer identified as Mazama (ca. 6600 years BP) by J.A. Westgate (pers. comm.). The overlying material (370 to 380 cm) yielded a date of

7750 - 180 years BP (Wat - 360).

A third sample (200 - 210 cm) was selected on the basis of pollen analysis, and marked an increase in arboreal pollen. This was dated at 4415 $\pm$ 165 years BP (GX-6233). The final sample (65 to 70 cm) was taken from a portion of the core marking a transition from gyttja to marl, and is still awaiting analysis at the new Simon Fraser radiocarbon dating laboratory.

Only one ash layer, identified as Mt. Mazama in origin, was found in the sediments, at 302 to 302.4 cm.

Phair Lake has a more complete set of dates provided by a total of 3 radiocarbon samples and 2 identifiable ash layers. The "basal" date was provided by 15 cm of dark silty clay (325 to 340 cm), originally thought to be rich in organic material but in fact quite poor in organics (see Chapter III). This yielded a date of 6780 $\pm$ 260 years BP (I-10,043), which may be somewhat young though it is not in conflict with the location of the Mazama ash at 302.5 to 305 cm.

A second radiocarbon sample was taken at 280 to 285 cm, within a bryophyte peat. This was dated at 5930 $\pm$ 115 years BP (I-9709), again consistent with the sample's position in relation to the Mazama ash. Well above this sample, at 143 cm, and within marly sediments is a thin layer of ash identified as Bridge River (ca. 2400 years BP) by J.A.Westgate (pers. comm.). This ash fall was not observed in Chilhil Lake. It may have been screened out by the Fountain Ridge, or may in fact be present but too diffuse to be noticeable, since Chilhil is a larger and more windswept lake.

The final sample comes from a shelly gyttja, just above a transition to marl (101 to 106 cm) and dates at 1985 ± 145 years BP (I-9708).

Accumulation rates for both lakes are shown in Fig. 7 which plots radiocarbon years BP against depth of sediment in centimeters.

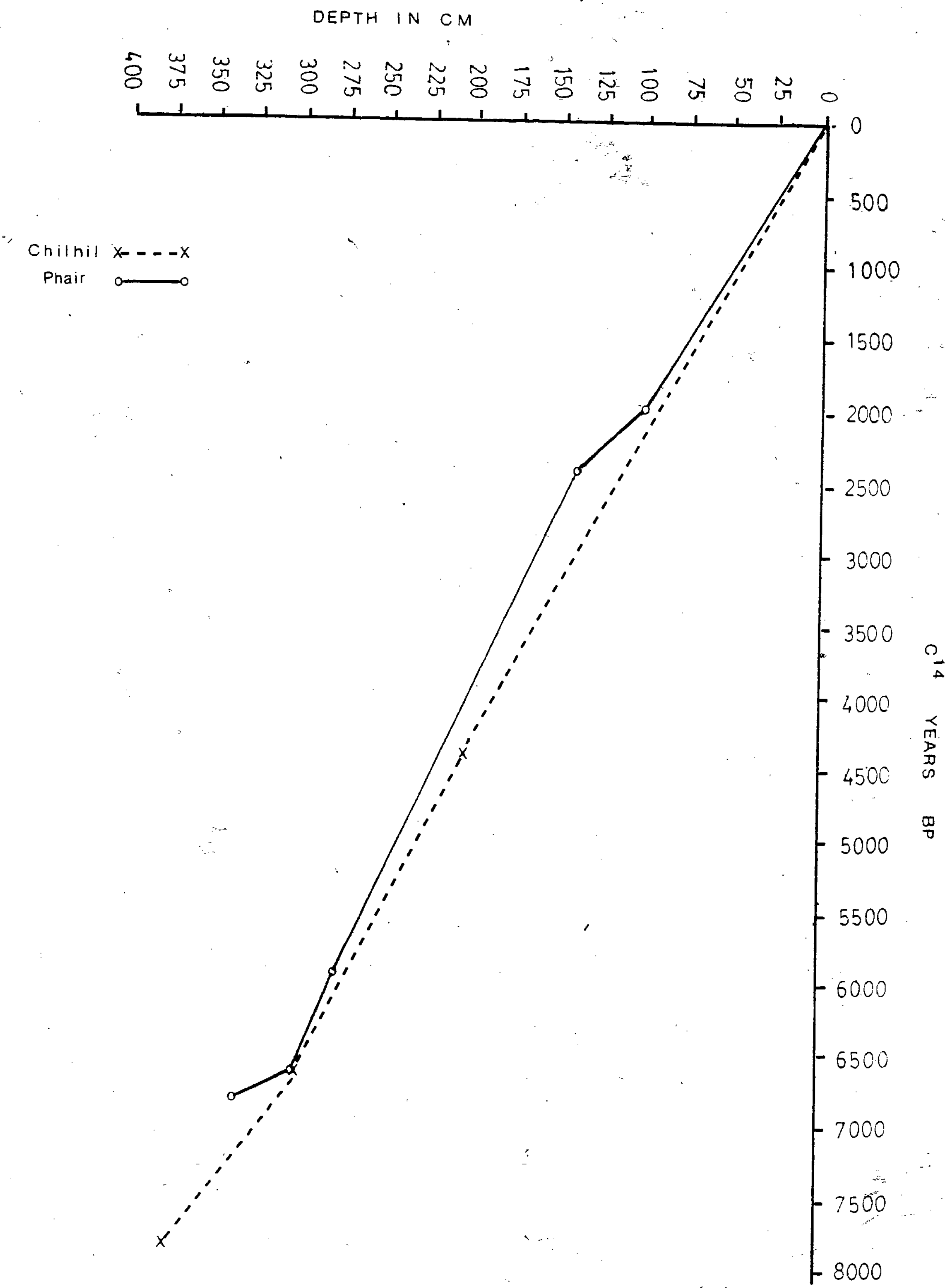
2.5 Data Analysis and Diagrams

Relative frequencies, concentrations and pollen influx values were calculated on the Simon Fraser IBM computer using a Fortran IV program, Polldata Mark 3, written by Drs. Birks and Huntley of Cambridge University.

The pollen sum used consisted of all upland species, categorized as Trees, Shrubs, and Herbs (including Pteridophytes). Some herbaceous species known to inhabit mudflats were included. Excluded were aquatic species, unknowns and indeterminable grains (those too broken or corroded to be identifiable). Cyperaceae were classified as aquatics although upland species may be present, since it is difficult to distinguish between Cyperads of different locales, and since the aquatic sedges would seem to be predominant. Those categories excluded from the pollen sum were calculated on a sum equal to the pollen sum plus the sum of themselves.

Thus a number of local and entomophilous species are included in the sum, despite some recommendations to the contrary (Wright and Patten 1963; Maher 1972). Janssen (1959, cited Wright and Patten 1963, p. 446) recommended the exclusion

Fig. 7 Sedimentation in Chilhil and Phair Lakes.


DEPTH IN CM
0
25
50
75
100
125
150
175
200
225
250
275
300
325
350
375
400
Chilhil x - - - - x
Phair o——o
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
6500
7000
7500
8000
C14 YEARS BP

of lake edge species such as _Alnus_. This was attempted for Phair Lake, where such species as _Alnus_, _Salix_ and _Betula_ comprise a large proportion of the pollen sum, but the resultant diagram was of little value. It would be necessary to use a much higher count per level, such as 400 non-local grains, before this might produce a reasonable diagram. This would not eliminate the problem of species such as _Betula_, which may be local in terms of their input at Phair Lake but which are also a component of the regional vegetation.

The inclusion of local and entomophilous species is here justified on the basis that for some species the counts per level are so low that inclusion makes little difference, that some of these species are actually widespread and a significant component of the vegetation though under-represented in the pollen (e.g., Rosaceae), and that some of these species reflect local conditions which may in fact be influenced by regional climatic conditions. Also, as Gordon and Birks (1972, p. 964) note, species with less than 5% of the pollen sum may be important in interpretation.

Also included in the pollen sum is a category entitled "Other Pollens". This includes herbaceous species represented by only one or two occurences in the core, and was set up to reduce the length of the pollen diagram. In Chilhil Lake, this category includes Boraginaceae, cf _Circaea_, _Gentiana_, _Linnaea borealis_, cf _Lysichiton americanum_, _Sanguisorba canadensis_, Scrophulariaceae, and Violaceae. In Phair Lake it includes Boraginaceae, _Gentiana_, Lamiaceae, _Polygonum_ cf _erectum_, _P._ cf _punctatum_, Scrophulariaceae, and Violaceae.

Pollen concentration was determined by adding a known quantity of exotic pollen (Eucalyptus) to a known quantity of sediment (1 cc), such that the number of fossil grains per unit sediment equals the number of exotics added times the number of fossil grains counted, divided by the number of exotics counted (Stockmarr 1971).

The concentrations are affected by loss of pollen due to incomplete processing ($\leq 1\%$), losses due to incomplete settling during centrifuging, and the sampling error introduced by the tablets, which is most significant and which widens the confidence interval to the point that small differences between samples are not interpretable (Bonny 1972). Stockmarr (1971) estimates the error resulting from use of the tablets at about 3% (which seems too low), and notes that as the pollen count increases, total error decreases but the percent of that error due to use of the tablets increases.

The concentration values were used to derive influx values, using the accumulation rates derived from the C^{14} dates and ash layers. Relative frequencies and influx values for those species found are plotted against depth in the diagrams, which were initially drawn by the computer. The influx diagrams use the same species as the diagrams of relative frequency, for calculating total tree, shrub and herbaceous pollen influxes, but a number of species with very small influx values are not plotted separately.

The macrofossils are diagrammed using histograms of raw counts of each species (expressed as numbers per approximately 98 cc of sediment) plotted against depth. Due to the great variation in the total number of macrofossils per level (ranging from 0 to greater than 1000), relative frequencies for the species found were not calculated. It was felt that the absolute numbers of macrofossils provided sufficient information for interpretation. Separate diagrams were constructed for plant materials and for molluscs.

Seeds and fruits were categorized as aquatics, mudflat and marsh species, and upland species, while other plant macrofossils (such as conifer needles) were placed in a separate category. Molluscs were divided into Pelecypoda and Gastropoda.

2.6 Zonation

The pollen zone boundaries are defined as "narrow stratigraphic segments characterized by large qualitative or quantitative changes in pollen spectra", separating pollen zones, which are "biostratigraphic units with internal consistency and differentiated by an assemblage of pollen types occuring with certain frequencies" (Yarranton and Ritchie, 1972). While there are a number of statistical techniques and computer programs designed to identify either boundaries or zones, various workers (e.g., Yarranton and Ritchie 1972; Gordon and Birks 1972) have found a good correspondence between zones selected on visual criteria and those generated by these other techniques. Zone boundaries in this thesis were drawn "by eye" where changes were obvious.

The zonation for both relative frequency and influx diagrams is based on the relative frequency diagram, although influx data would seem to support a slightly different zonation in Phair Lake. However, these influx values may be unreliable due to difficulty in ascertaining rates of accumulation below the Mazama ash in Phair Lake.

Macrofossil diagrams were zoned independently of the pollen data and of each other, also by visual inspection.

Zones are designated by the initials of the site. Thus pollen zones are labelled PhL for the Phair Lake pollen diagrams and CL for the Chilhil diagrams. Macrofossil zones for these lakes are designated by PhLP and PhLM (Phair Lake plant remains and Phair Lake molluscs, respectively), and CLP and CLM (Chilhil plant remains and molluscs).

3. RESULTS

3.1 Phair Lake

Sediment Stratigraphy and Dating

The basal portion of the core consists of an almost pure blue gray clay (argilla steatodes; Troels-Smith 1955) suggestive of ice contact, or possibly input from some high altitude melting glacier. From about 340 cm depth up to 320 cm, this clay becomes increasingly dark, almost black. At first this blackish colour was ascribed to organic content, however analysis of the sediments indicated that the material is in fact a black silt. Water content is low, averaging 25.5% (see Fig. 8), as are loss on ignition (averaging 1.85%) and ash values (averaging 3.1%; both this and L.O.I. are expressed as % of dry weight in Fig. 8). Particle size separation was also carried out for some of this material and the results (Table 2) again support the contention that this is a silty clay.

A radiocarbon date from this sediment required 15 cm of core to obtain sufficient carbon for dating. Extrapolating from this date of 6780 $\pm$ 260 years BP (I-10,045) produces a basal date of 7050 years BP. The carbon date may be somewhat too young, since it suggests a sediment deposition time of approximately 6.67 years per centimeter for the entire section of core below the Mazama ash. In particular, it suggests that only 180 years were required for the accumulation of 27 cm of material, 10 cm of which represent peat. While it is possible

Table Two

Particle size analysis
of two basal clay segments of the
Phair Lake core

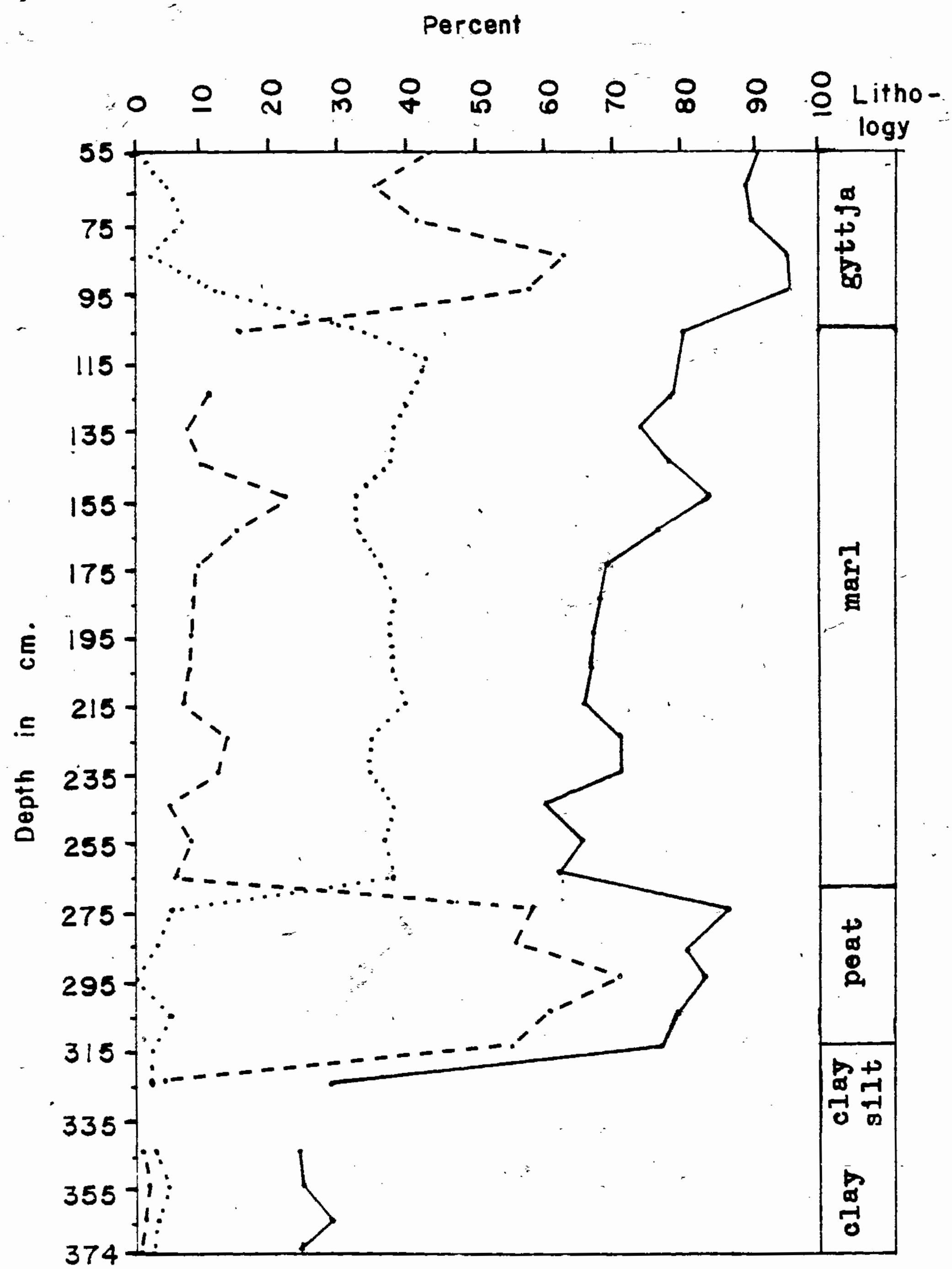
Particle size	% of volume 316-320 cm	% of volume 320-325 cm
< 250 microns	21.7	27.0
250 to 75 microns	50.0	31.1
>75 microns	28.3	41.9

that there was an exceedingly rapid input of silt between about 330 and 315 cm, it seems likely that there is an error in the accumulation rate.

At 315.6 cm, the sediment changes abruptly. There is a layer of wood (detritus lignosa, Troels-Smith 1955), which may mark a hiatus in the deposition of sediments, superceded by a moss peat (turfa bryophytica, Ibid.), which contains some large fragments of wood and herbaceous matter. As is expected, both water content and loss on ignition values increase sharply within this spongy organic material (averaging 81% and 59.5% respectively). Ash weights remain low (about 2.9%).

There are two dates within this peat layer, which is 42 cm thick. One is provided by the Mazama ash (302.5 to 305 cm) and the other by a C^{14} sample from a depth of 280 to 285 cm (near the top of the peat; see Fig. 7). The deposition rate between these dates is approximately 33.5 years per cm. Therefore, if one assumes a constant rate of

Fig. 8 Analysis of Sediments from Phair Lake. Loss on ignition and ash values expressed as percent of dry weight.



—— water content

- - - - loss on ignition

····· loss on ashing

deposition throughout the peat, one can estimate that peat deposition began ca. 6935 years BP and ended ca. 5645 years BP. This suggests that if the lowermost C^{14} date is correct, the actual date must be very close to the oldest estimate given (6780 + 260 years BP), and the basal date is approximately 7260 years BP.

At 274 cm there is a layer of fine, almost matted detritus, which may represent a hiatus in deposition. Above this is an abrupt shift to a shelly marl (limus calcareous; Troels-Smith 1955), which continues to 106 cm. It is light tan in colour and contains laminae of varying thickness. Some are reddish in colour, perhaps suggesting oxidizing conditions, and a few thin layers are black. These latter seem to be associated with the presence of mollusc shells, and may represent a fire and/or erosion zone marking a greater influx of terrestrial materials. There is a definite fire zone at 254.5 cm consisting of charcoal and felted detritus.

The marl is characterized by the presence of shells (Troels-Smith's testae molluscorum, 1955), and by low loss on ignition and therefore organic carbon values, and high inorganic carbon values as indicated by the loss on ashing (averaging 36.3%). Water contents are moderate, decreasing with increasing depth (from about 79% to 61%) reflecting increasing compression of the sediments.

The date provided by the Bridge River ash at 143 cm gives an accumulation rate of approximately 25.3 years per cm below the ash; 24.75 years per cm if one excludes all peat from this calculation and considers only the marly deposits.

At 106 cm there is yet another rapid change in sediment type, from marl to a dark olive-brown gyttja (limus detrituosus, Troels-Smith 1955). A radiocarbon sample dates the start of this deposit at 1985 ± 145 years BP (I-9708). This yields a deposition time of about 10.4 years per cm in the 37 cm of marl above the Bridge River tephra. The apparently more rapid deposition of materials in this upper portion of marl may be a product of the lesser compression of these sediments, or it may reflect an uneven rate of deposition, as suggested by the presence of the laminae.

The gyttja has a high water content, averaging about 92%. The uppermost sediments were, in fact, almost totally liquid, but no samples were taken from the Brown core for sediment analysis. Loss on ignition values for the gyttja were on average fairly high (47%) and ash values were low (averaging 5.1%).

The average accumulation rate above the upper C^{14} date is about 19.2 years per cm, though the loose, uncompacted upper sediments probably represent a much shorter span of time.

Pollen Stratigraphy

Pollen preservation begins at about 320 cm. Below this depth sediments are essentially sterile, and most of the few pollen grains found are corroded, suggesting a rapid rate of deposition. It may also be that a surface suitable for pollen deposition and preservation was not formed until some time immediately prior to the Mazama ash fall.

Only two pollen zones are identified in the relative frequency and pollen influx diagrams (Figs. 9 and 10). Zone PhL-1 (320 to 290 cm) is characterized by relatively low percentages of arboreal pollen (AP), particularly Alnus and Betula, with peaks in Pinus and Abies. There are also high values of grass pollen and some Pteridophyta spores, notably Equisetum and Pteridium aquilinum, the bracken fern. It is the aquatic pollen, however, which truly differentiates this zone - in particular the high percentages of Cyperaceae and Typha latifolia. Equisetum spores might also represent an emergent aquatic horsetail, such as E. fluviatile (see Discussion).

Zone PhL-2 occurs above 290 cm (ca. 6180 years BP), from which point the overall pollen profiles are rather complacent. Both pine and alder show wide level to level fluctuations (from 10 to 40%), high values of Alnus usually coinciding with low values of Pinus, but no trends are apparent.

Few trends are noticeable in the non-arboreal pollen (NAP), except for the slight increase in Artemisia in the bottom third of this zone, and decline in Artemisia and Poaceace above this point. Equisetum, Cyperaceae and Typha decline.

It is possible to recognize an upper subzone, perhaps representing disturbance within this zone, from about 20 cm to 0 cm depth, which is marked by reductions in Pinus, Pseudotsuga and Alnus percentages, and an increase in Betula. There is also a slight increase in Cupressaceae and Populus tremuloides pollen, but this probably reflects differential preservation (Sangster and Dale 1961). Among other categories,

Fig. 9 Phair Lake pollen percentage diagram.

Unshaded portion of curves indicates 10Xs exaggeration.

there are small peaks in pollen of the shrubs *Spiraea* and *Corylus*, as well as herbaceous Fabaceae. Assuming a constant rate of deposition, this subzone would date from about 385 years BP. However, considering the loose and uncompacted nature of these layers, it seems likely that this date is too old.

The same zonation is applied to the influx diagram (Fig. 10). Zone PhL-1 is characterized by high influx values of Cyperaceae and *Typha latifolia*, and the tree species *Pinus* and *Abies*. There are also peaks in influx of *Picea* and *Pseudotsuga menziesii*, though these are not reflected in the relative frequencies.

In PhL-2 there is a gradual increase in total influx as one moves upwards in the core, declining again rapidly in the upper 50 cm. There are two major peaks in influx. One is found at about the level of the Bridge River ash, and is made up largely of *Alnus* and *Betula*, two local species. The other is found at a depth of about 80 cm in the gyttja, and is produced by an increase in the influx of all upland species. This suggests an increase in the deposition or preservation of the palynomorphs, and since there is no change in sediment at this point, one might suggest that this peak is in fact due to increased inwashing of palynomorphs via precipitation or wind. The very small increases in *Abies* and *Picea*, two high elevation species, indicate that wind is not the key factor.

It might be noted that using primarily relative frequencies of *Equisetum*, Cyperaceae and *Typha latifolia*, the zone boundary

Fig. 10 Phair Lake pollen influx diagram (selected pollen and spore types).

Unshaded portion of curves indicates 10Xs exaggeration.

should obviously be placed at 275 cm, corresponding to the upper limit of the peat layer.

Macrofossil Stratigraphy

Zonation of the plant macrofossil diagram (Fig. 11) is simple. Zone PhLP-1, below 325 cm, is characterized by a paucity of material. Macrofossils found consist almost entirely of wood fragments and rootlets, three fragments of Pseudotsuga needles and one Pinus ponderosa needle.

Zone PhLP-2 corresponds to zone PhL-1 of the pollen diagrams (325 to 290 cm), and is marked by an abundance of Scirpus achenes, as well as occasional Potamogeton (Plates 1a and 1b) and Carex cf comosa.

Zone PhLP-3 corresponds to pollen zone PhL-2 (290 to 0 cm) and is characterized by the seeds and fruit scales of Betula papyrifera and B. occidentalis, as well as by the consistent presence of Pseudotsuga menziesii needle fragments.

The mollusc record (Fig. 12) is somewhat more complex. Below 275 cm (zone PhLM-1) mollusca are generally absent.

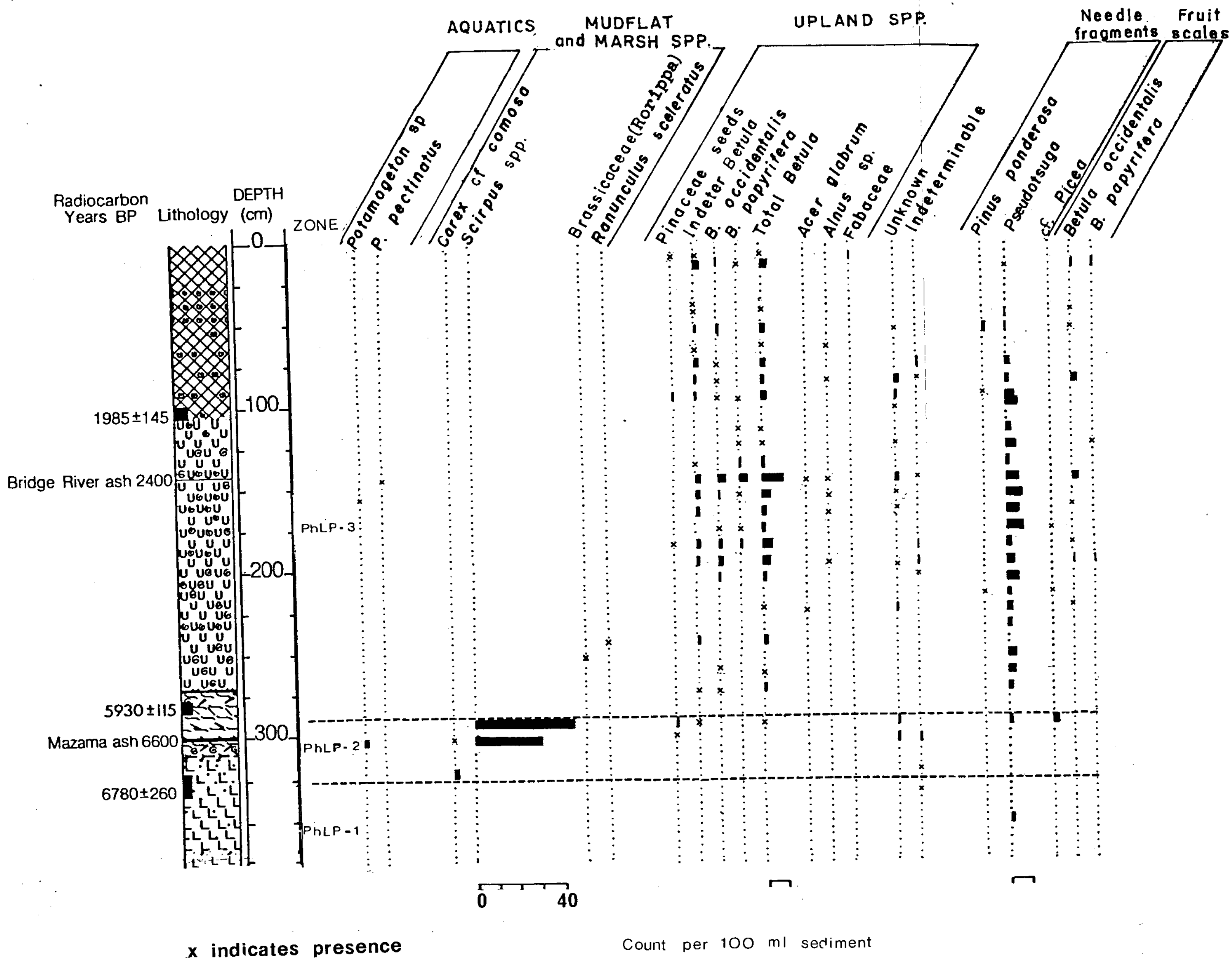
Zone PhLM-2 extends from approximately 275 cm to 110 cm, or the full extent of the marl. This zone is divided into three subzones. PhLM-2a (275 to 210 cm, about 5650 to 4050 years BP) contains relatively large numbers of the Pulmonates Gyraulus deflectus and immature Helisoma species, and moderate numbers of Pelecypoda.

Subzone PhLM-2b (210 to 145 cm) is characterized by large numbers of Pelecypoda, and few of any of the Gastropoda,

Fig. 11 Phair Lake plant macrofossil diagram.

For key to Lithology, see pollen diagrams (Figs. 9 and 10).

Fig. II PHAIR LAKE PLANT MACROFOSSIL DIAGRAM



with the exception of some immature Lymneids near the lower part of this subzone. In subzone PhLM-2c (145 - 110 cm 2400 to 2000 years ago), the number of Pelecypods declines, while Gyraulus deflectus and immature Helisoma species increase slightly, and H. cf corpulentum, Physa jennessi skinneri, cf Lymnaea species and Valvata sincera helicoidea all peak.

Zone PhLM-3 might also be divided into three subzones, the lower (110 to 50 cm) and upper (25 to 0 cm) lacking any molluscs. Some molluscs, mainly Pelecypoda, Gyraulus and Valvata are found between 25 and 45 cm (about 480 to 860 years BP).

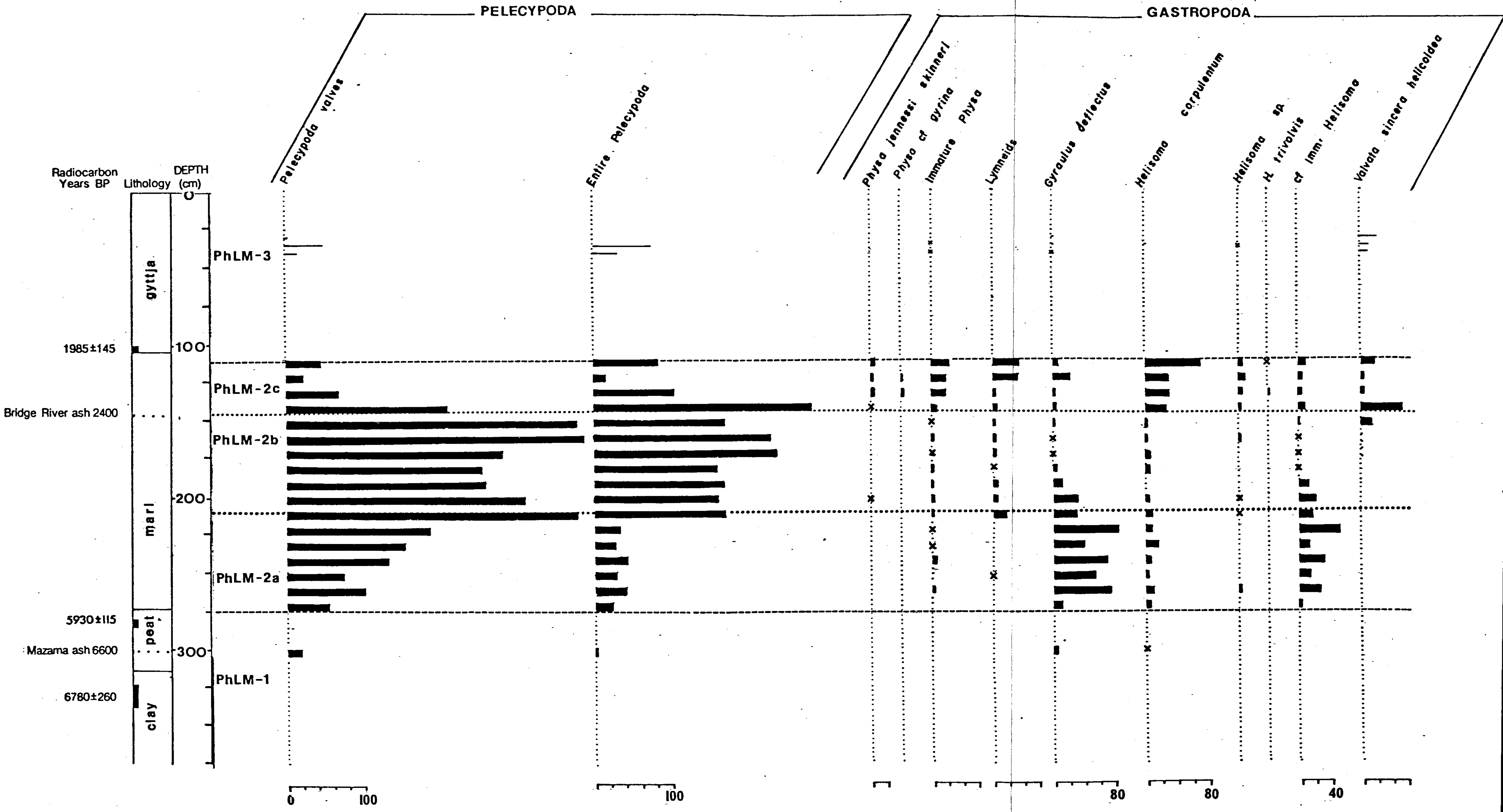
The molluscan stratigraphy seems to correspond more closely with the sedimentary column than do the pollen data, as might be expected.

Phair Lake Surface Samples

The results of analysis of the eight soil surface samples and the one moss polster are included in Appendix 2 (Table 3), along with percent cover values for the 1 m^2 quadrats from which the samples were taken. The relationship between percent cover and representation in the soil pollen assemblage is not constant, due in part to the nature of pollen dispersal of some species, and the inadequacy of using a 1 m x 1 m quadrat to estimate the input of tree species. In some cases, a very high percentage cover is related to high pollen percentages (e.g., Betula in samples 7 and 8 from the vicinity of the input stream). In a number of cases species not actually in the

Fig. 12 Phair Lake mollusc diagram.

Fig. 12 PHAIR LAKE MOLLUSC DIAGRAM



x indicates presence

Count per 100 cc sediment

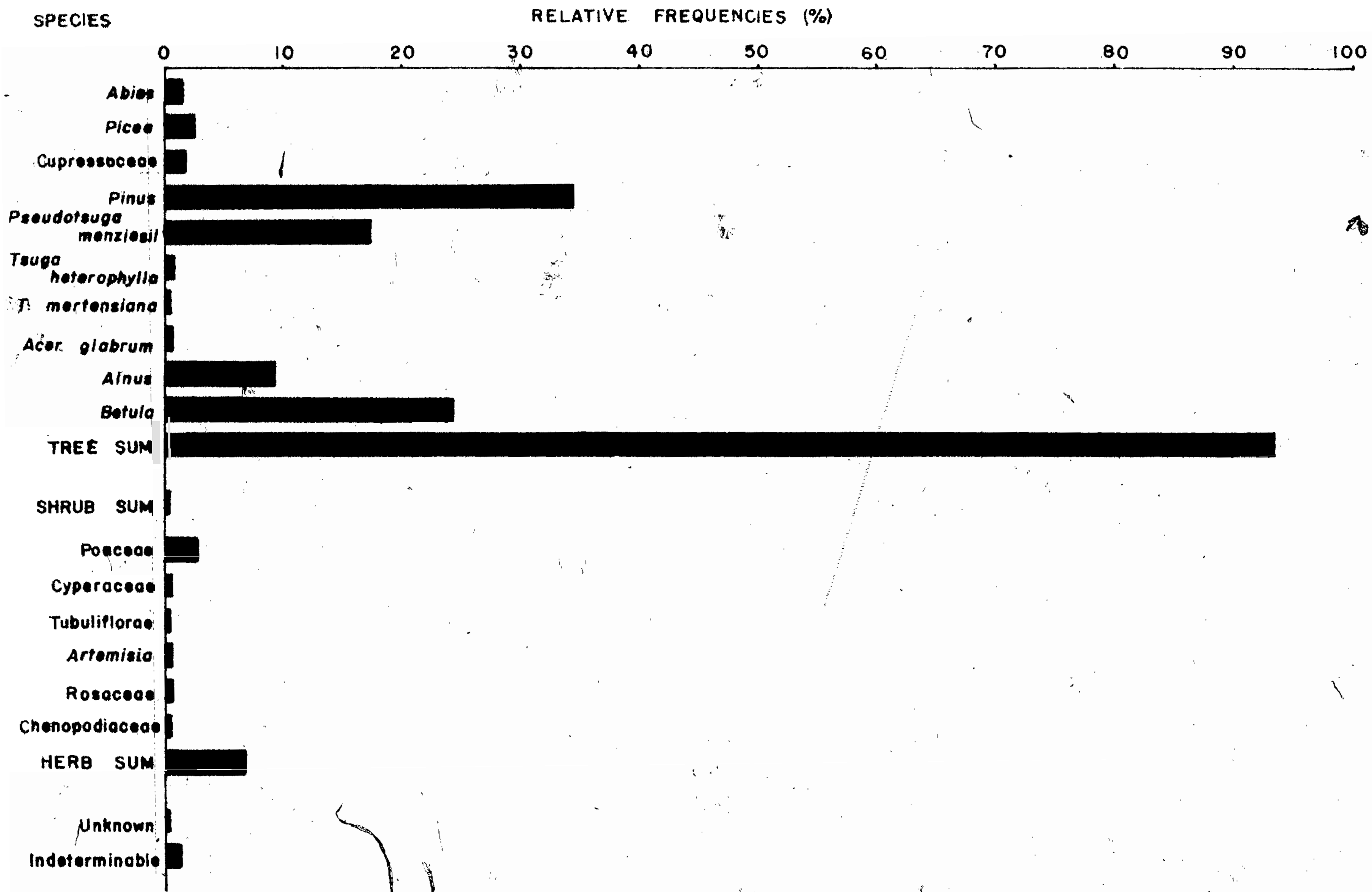
quadrat but nearby contributed greatly to the soil pollen. Some species (e.g., Abies, Picea, Tsuga mertensiana, and Pinus albicaulis type) are obviously present as a result of transport from higher elevations.

In some of the samples, insect pollinated or poor pollen-producing species are represented in the assemblage. Sometimes, though not always, this was related to the presence of these species within the quadrat. In this case, the percentage representation in the pollen is generally much less than the percent cover, due to the presence of species nearby which are large pollen producers. Also, some species (e.g., Galium) are not represented in the pollen record even when present on the site of the sample.

To overcome the problems of local over-representation of some species and more closely approximate the incoming pollen rain, the surface samples were aggregated to produce a single histogram of pollen frequencies from the vicinity of Phair Lake (Fig. 13), as recommended by Adam and Mehringer (1975).

Fig. 13 Phair Lake surface samples, aggregate diagram.

PHAIR LAKE SURFACE SAMPLES AGGREGATE DIAGRAM



3.2 Chilhil Lake

Sediment Stratigraphy and Dating

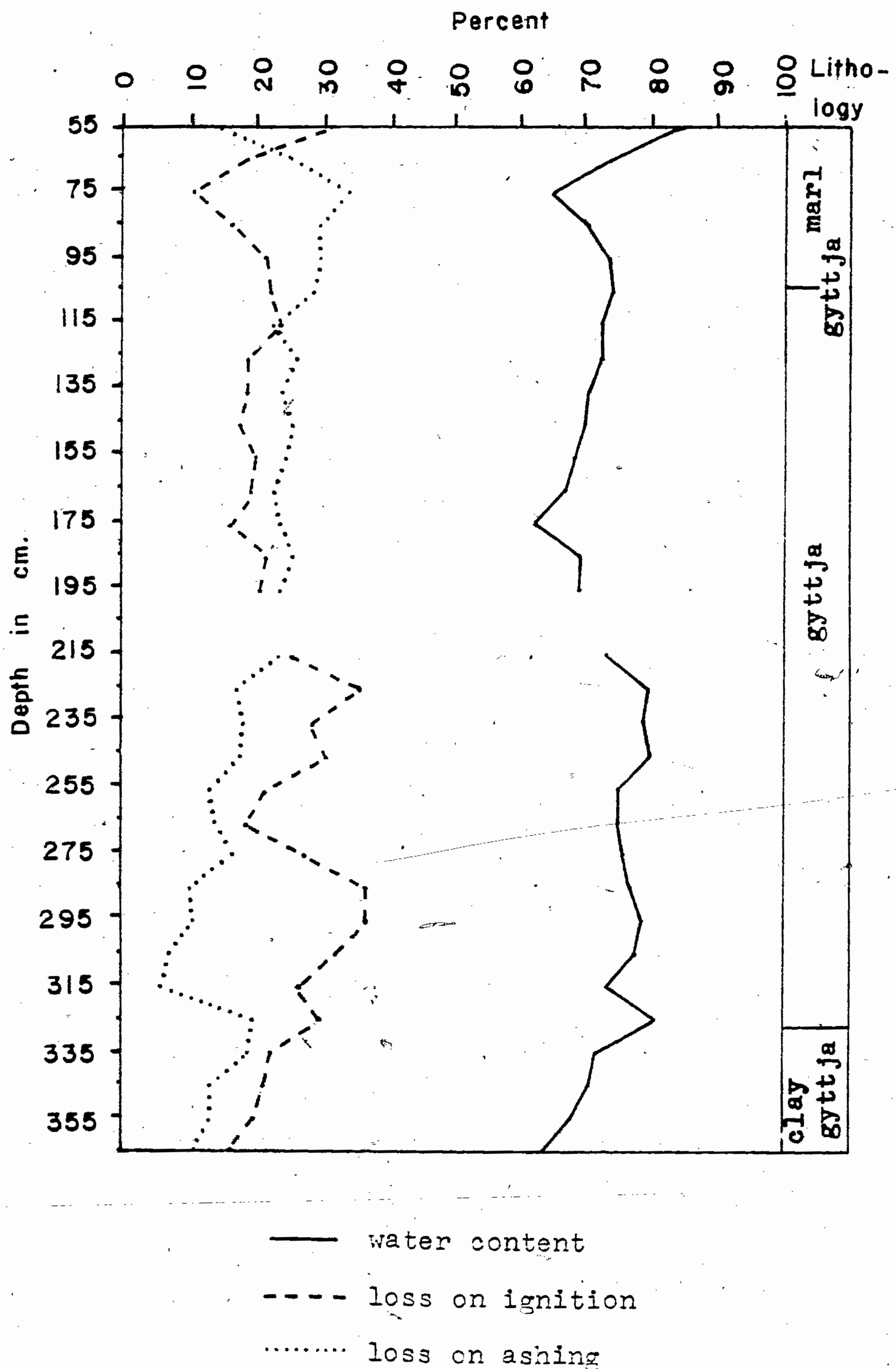
The basal material (380 to 390 cm) consists of a stiff, grey clay-gyttja. A radiocarbon sample from this material produced a date of 4860 ± 120 years BP (I-10,044), which was defined as anomalous because it occured well below the Mazama ash known to date at approximately 6600 years BP.

Above 380 cm the clay becomes increasingly brown in colour and dominated by gyttja until by 325 cm the sediment is an almost pure gyttja. A radiocarbon sample taken from the clay-gyttja at 370 to 380 cm provided a date of 7750 ± 180 years BP (WAT-360). By extrapolation of accumulation rates, the very basal sediments date from about 7986 years BP (range from 7760 to 8166 years BP).

The sediments are very uniform, with gyttja extending to about 104 cm, above which level increasing amounts of marl are present. There are variations in colour, the abundance of molluscs, and the presence of herbaceous detritus. Shells are particularly abundant between 104 cm and 221 cm, and plant fibres are abundant below this level. There is a band of very dark, almost black gyttja between 221 and 230 cm which contains fine organic matter.

The sediment analysis reflects the general uniformity of the gyttja (see Fig. 14). Water content remains fairly uniform to a depth of about 325 cm (averaging 73.7%), below which depth it decreases steadily, due to increasing proportions of clay and silt, and increasing compression of sediments.

Fig. 14   Analysis of sediments from Chilhil Lake. Loss on ignition and ash values expressed as percent of dry weight.


Percent
0
10
20
30
40
50
60
70
80
90
100
Litho-
logy
Depth in cm.
55
75
95
115
135
155
175
195
215
235
255
275
295
315
335
355
marl
gyttja
gyttja
clay
gyttja
water content
loss on ignition
loss on ashing

Loss on ignition percentages (indicating organic carbon) averages around 25.4%. It increases below 210 cm, as does herbaceous detritus. A small peak in L.O.I. at 225 cm corresponds with the blackish layer mentioned above.

Loss on ashing values average 19.5% and tend to be lowest where L.O.I. values are highest. There seems to be, in general, an inverse relationship between L.O.I. and ash values in this core, until a depth of 325 cm, below which both decline steadily as silt and clay contents increase. It might be noted that water contents and L.O.I. values are lower, and ash values higher in Chilhil than in the Phair Lake gyttja.

There are two dates from within this sediment. One is provided by a layer of Mazama ash at about 302 cm depth, and the second is a C^{14} sample taken from a depth of 200 to 210 cm. This date, 4415 $\pm$ 165 years BP (GX-6233), marks both an increase in Pine pollen percentages and a decrease in organic carbon within the sediments as one moves upwards in the core.

Based on these dates, sediment deposition times are approximately 15.75 years per cm below the ash, 22.5 years per cm between the ash and the upper radiocarbon sample, and 21.54 years per cm above this sample. Using these values the appearance of increasing amounts of marl at 102 cm dates at about 2196 years BP, and the occurence of a band of pure shelly marl between 90 and 70 cm at 1937 to 1506 years BP. The stratum of marl is characterized by lower water contents (about 68%) and L.O.I. values (14%) and higher ash values (32%) than the gyttja, a pattern also found in the Phair Lake marl.

Fig. 15. Chilhil Lake pollen percentage diagram.

Unshaded portion of curves indicates 10Xs exaggeration.

Above the marl there is a transition back to gyttja, and a loose dark olive-grey gyttja occurs from about 45 cm to the surface. A third radiocarbon sample which would confirm or negate the dates suggested for marl deposition was submitted for dating.

Pollen Stratigraphy

Palynomorphs are present in all sediments sampled, including the basal clayey materials. Three pollen zones have been identified (Figs. 15 and 16).

Zone CL-1 extends from the basal sediments to 330 cm (about 7042 years BP) and is characterized by relatively low arboreal pollen values (between 53% and 73%). *Pinus* ranges from about 29% to 52%, *Picea* and *Pseudotsuga* are less than 5% of the total; and *Tsuga heterophylla* and *Acer glabrum* just appear in this pollen zone, the former reflecting long distance transport (see Discussion), and the latter a local occurence. Non-arboreal pollen values are high, due to high counts of *Artemisia*, a small peak in Tubuliflorae, increasing amounts of Poaceae (to a maximum of about 15% at 360 cm), as well as peaks in *Rumex*, Brassicaceae, Chenopodiaceae (to 19% at 395 cm), and spores of *Pteridium aquilinum*. Influx values for these species also indicate peaks, and overall influx values average 2528 grains per cm^2 per year.

Zone CL-2 (330 to 205 cm) might be described as transitional. Arboreal pollen frequencies gradually increase from values of between 61% and 72% near the bottom to better than 83% at the top of the zone. Little of this increase is a product of increasing pine values. Most of it is a result of gradual increases in Pseudotsuga menziesii (to a maximum of 11% near the top of the zone), and Picea, as well as slight increases in Populus, Cupressaceae, and Tsuga heterophylla pollen. Alnus values are consistently high.

This zone could be subdivided into three subzones. A subzone CL-2a (330 cm to 300 cm, just above the Mazama ash) is characterized by a peak in Pine pollen and the disappearance of Chenopodiaceae. Subzone CL-2b (about 300 cm to 275 cm, ca. 6550 to 5985 years BP) is marked by reduced Pine values, increases in both Chenopodiaceae and Rumex pollen, and a peak in Typha latifolia. In the third subzone, CL-2c (275 to 205 cm), Pinus, Pseudotsuga and Picea percentages increase, and Salix peaks. Artemisia and Poaceae, which until this point had remained fairly high, begin to decline. Chenopodiaceae levels again drop significantly. There are also peaks in percentages of three aquatic species, Potamogeton, Myriophyllum and cf Sparganium.

This threefold division is not at all marked in the Influx diagram (Fig. 16); only the peak in Myriophyllum pollen is unequivocal in the latter. In general, influx values are lower than in zone CL-1, averaging about 1720 grains per cm^2 per year.

In the upper zone, CL-3 (205 or 4415 years BP, to 0 cm) arboreal pollen values are consistently high, largely as a result of an increase in values of Pinus. All other tree species remain fairly constant, with the exception of Alnus, which declines slightly, and Tsuga heterophylla, which has

Fig. 16 Chilhil Lake pollen influx diagram (selected pollen and spore types).

Unshaded portion of curves indicates 10Xs exaggeration.

increased slightly from zone CL-2. The tree sum ranges from about 75% to 88%, dropping in the upper 75 cm.

The most important herbaceous genera are Artemisia, Chenopodiaceae, and Poaceae, but their values are much reduced from the preceding zone. Important aquatics are Cyperaceae and Myriophyllum.

This zone might also be subdivided, with subzone CL-3a (205 to 75 cm) as described above, and subzone CL-3b above 75 cm characterized by a drop in Pinus percentages to a minimum of 41% and increases in Poaceae from about 6% to 15%. The upper 25 centimeters are also distinguished by small peaks in Tubuliflorae, Liguliflorae, Brassicaceae, Fabaceae, and Polygonum erectum type pollen. Cyperaceae all but disappear, and there are peaks in the percentages of Polygonum cf amphibium, Potamogeton and Myriophyllum.

This naturally does not show up in the influx diagram, since no correction of rate of deposition was applied to the very loose upper sediments. Influx averages about 2740 grains per cm^2 per year below 50 cm, and only about 1064 grains per cm^2 per year above that level.

Macrofossil Stratigraphy

The boundaries of the pollen zones match with only a little modification the zonation of the plant macrofossil diagram (Fig. 17). Zone CLP-1 (from 330 cm to 370 cm, the bottom 20 cm of the core having been used for radiocarbon dating and therefore not available for macrofossil analysis) is

Fig. 17 Chilhil Lake plant macrofossil diagram.

For key to Lithology, see pollen diagrams (Figs. 15 and 16).

characterized by high values of *Potamogeton* achenes, some *Zannichellia palustris* (Plate 1j) and one small peak in *Alisma* achenes (Plate 1c), among aquatic species. Also numerous are fruits and achenes of *Rumex maritimus* (Plate 1e), achenes of *Ranunculus sceleratus* (Plate 1d), lenticular Cyperaceae (Plage 1g), cf *Scirpus*, and especially seeds of Chenopodiaceae (Plate 1h).

Zone CLP-2 is, like CL-2 in the pollen diagrams, a transition zone, extending from 330 cm to about 190 cm. Like its counterpart, this macrofossil zone also lends itself to subdivision, but perhaps only into two subzones. The lower subzone CLP-2a (330 to 245 cm) contains initially high values of *Potamogeton* and Chenopodiaceae, which then decline. At 280 cm , there are peaks in *Zannichellia palustris*, lenticular *Eleocharis* species, *Ranunculus sceleratus*, *Rumex maritimus*, and Chenopodiaceae. This is the equivalent of pollen subzone CL-2b, but in this diagram it occupies a single level. Above this peak these species all but disappear. Subzone CLP-2b (245-190 cm) is characterized by abundant achenes of *Najas flexilis* (Plate 1i).

In Zone CLP-3 (190 cm to 0 cm), *Najas* all but disappears, and larger numbers of *Potamogeton*, *Zannichellia palustris*, *Ranunculus sceleratus* and Chenopodiaceae reappear, though these do not approach their abundance in zone CLP-1. Lenticular Cyperaceae all but disappear, and *Scirpus* achenes make their first major appearance.

There is a lack of macrofossil material between 75 and 90 cm (the marl), then the macrofossils reappear, only to decline

Fig. 18 Chilhil Lake mollusc diagram.

For key to Lithology, see pollen diagrams (Figs. 15 and 16).

again in the looser upper sediments.

The zonation of the mollusc diagram (Fig. 18) differs somewhat. Zone CLM-1 (370 cm to 215 cm, encompassing a period from about 7670 to 4640 years BP) contains virtually no molluscs, with the exception of a few Lymneids, Gyraulus deflectus, immature Helisoma sp. and Promenetus sp. found between 350 and 370 cm.

Zone CLM-2 (215 to 0 cm) is marked by an abundance of mollusca, and can be subdivided into three subzones. Subzone CLM-2a (215 to 105 cm, or about 2260 years BP) has low to high values of Pelecypoda, and high counts of Lymneid species, Gyraulus deflectus, Helisoma and Promenetus species.

Subzone CLM-2b begins at a point where marl contents in the gyttja becomes noticeable, and continues to 60 cm, or about 1300 years BP. This subzone is dominated by Pelecypoda, which reach their highest values in the core here, as well as Gyraulus deflectus, Helisoma cf corpulentum, and two species which first appear in this subzone, namely Valvata sincera helicoidea and Physa jennessi skinneri. Promenetus and Lymneids are also present.

The final subzone, CLM-2c, begins with the deposition anew of increasing amounts of gyttja. In this section of core, molluscs are much less abundant, and Helisoma species all but disappear. The absence of molluscs may be due to the type of sediment, or may in fact be due to their loose, uncompacted nature, especially above 40 cm. This also suggests that the molluscan assemblage may not represent a single relatively short period of deposition, but may be a temporal composite, due to the sinking of heavier shells into a loose substrate.

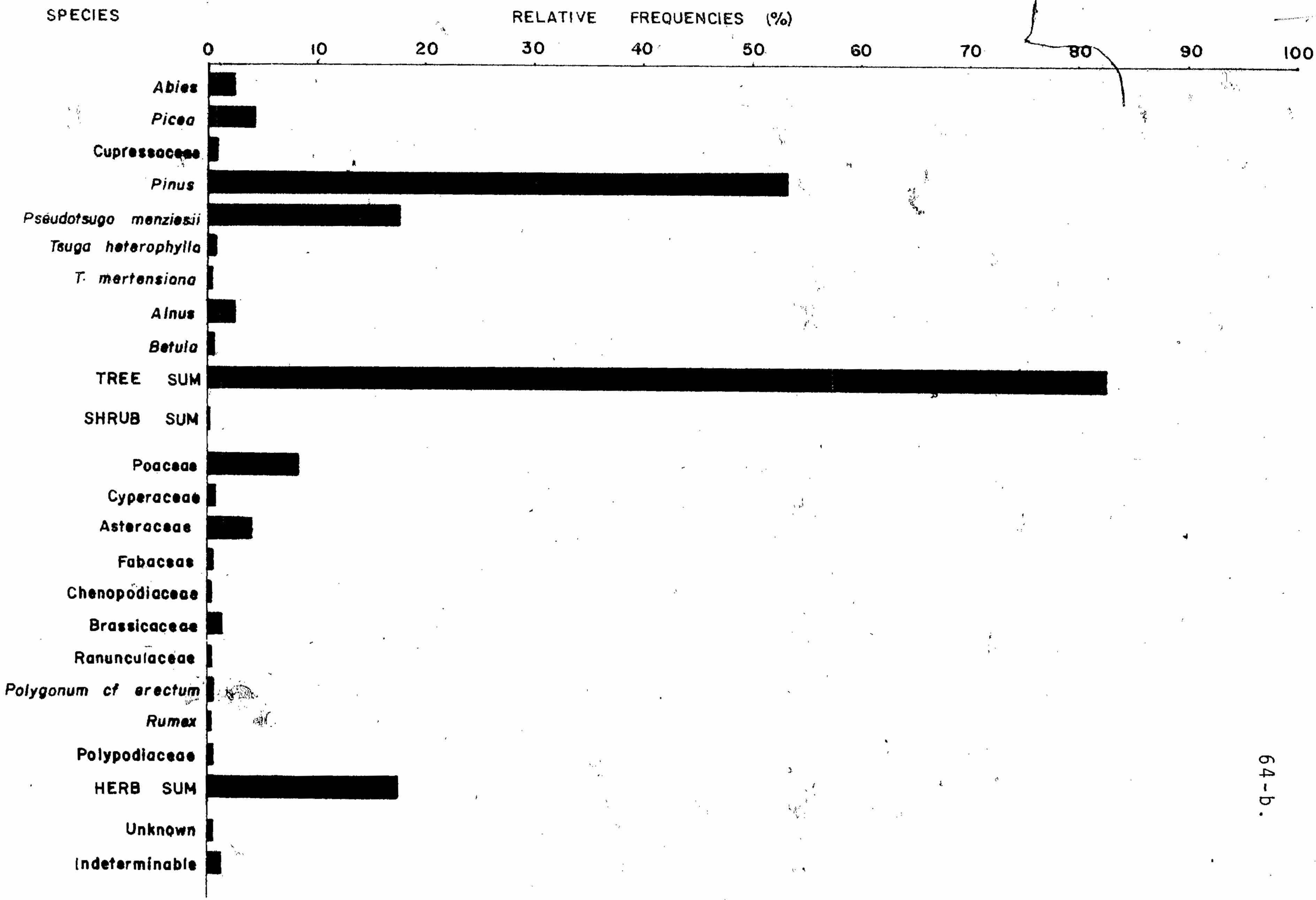
Chilhil Lake Surface Samples

A total of nine surface samples were analysed from around Chilhil Lake, seven soil samples and two moss polsters. Percent cover data were not gathered from these sample sites, but the general nature of the vegetation was noted. The pollen relative frequencies are given in Table 4 in Appendix 2.

As for the Phair Lake data, the results of analysis of the samples were aggregated to produce a single composite histogram (Fig. 19).

Fig. 19 Chilhil Lake soil surface samples, aggregate diagram.

CHILHIL LAKE SURFACE SAMPLES AGGREGATE DIAGRAM



4. DISCUSSION

4.1 Vegetation History

Introduction

There was almost perfect correspondence between pollen zones and plant macrofossil zones, though these were set up wholly independently of each other, in both Phair and Chilhil lakes.

Phair Lake

Zone PhLP-1 and the pollen-poor basal sediments below 320 cm consist of a black silty clay which merges into a blue-grey clay. Even after processing with Sodium pyrophosphate and HF to remove silicates, fewer than 20 pollen grains per slide were found, and most of these tended to be greatly corroded or broken. A count of 100 pollen grains at 320 cm required scanning five slides, and produced an assemblage consisting of *Pinus*, *Pseudotsuga menziesii*, cf Cupressaceae, *Alnus*, Poaceae, *Pteridium aquilinum*, Polypodiaceae and single grains of *Picea*, *Betula*, Tubuliflorae, Fabaceae, and Ranunculaceae. There were also a number of unknown and indeterminable palynomorphs.

The macrofossil zone (325 to 374 cm) is essentially sterile, with the exception of some rootlets, a fragment of a *Pinus ponderosa* needle at 370 to 374 cm, and three fragments of *Pseudotsuga* needles at 350 to 355 cm.

The radiocarbon date from this sediment suggests that the low pollen concentration is due to a very rapid rate of deposition, resulting in influx values of less than 250 grains per cm^2 per year. The corroded nature of the pollen suggests some inwashing of terrestrial materials, but this is contradicted to some extend by the lack of macrofossils.

It is possible that the basal clayey sediments actually represent a period when there was little vegetation to contribute either pollen or macrofossils, but this is not supported by the record which does exist. The presence of *Pinus ponderosa* and *Pseudotsuga* needle fragments suggests that these species were present in the vicinity of the site. It seems more likely that the blue gray clays were a product of ablation of high elevation glaciers, the meltwater of which fed into Phair Lake. The lack of varves is explained by the probable shallowness of the water body.

Assuming a constant rate of accumulation within a sediment type, this zone dates from about 7000 to 7260 years BP.

Zones PhL-1 and PhLP-2 extend from about 320 cm depth (325 cm in the macrofossil diagram) to 290 cm, circa 6180 years BP. The pollen zone is characterized by maximum values in *Pinus*, *Abies* and *Picea*, both in terms of relative frequencies and influx values. *Pseudotsuga* values are moderately high, and *Alnus* and *Betula* are at their minima.

Despite high percentages for some tree species, total arboreal pollen is at its lowest in the core, ranging from 51.4% to 81% (averaging about 65.5%). The high non-arboreal pollen total (averaging 34.5%) is made up largely of grains of *Salix*, Poaceae, *Equisetum*, *Pteridium aquilinum* and Polypodiaceae. Although the NAP percentages are similar to those measured in grassland-forest transitions areas in the nearby Hat Creek Valley (Hebda 1979, unpubl.), the species composition is unlike any modern transitional assemblage. Instead, the above herbaceous species plus Typha latifolia and Tubuliflorae are typical of bogs (McAndrews 1967) and marshes. The sediment type is a moss peat containing wood and herbaceous detritus. Some of the wood was identified as coniferous.

Boggy conditions with shallow water are suggested by sediment type, pollen, as well as macrofossils. Nearly all the plant macrofossils found belong to the Cyperaceae (Carex cf comosa and Scirpus species), coinciding with peaks in Cyperaceae pollen. There are also remains of Betula, and a few conifer needle fragments, including cf Picea, which may indicate spruce growing on or near the marsh. This would explain the higher relative frequencies and influx values of this taxon in this zone.

Achenes of Potamogeton and Chara oogonia suggest that while the lake may have been much reduced in depth, there was still some open water, at least 0.7 m deep based on the ecology of Chara (Rawson 1934).

Zones PhL-2 and PhLP-3 extend from 290 cm to the surface. Here the pollen diagram becomes fairly complacent, with wide level to level fluctuations in some species (e.g., Pinus and Alnus) but no marked trends. Arboreal pollens have increased to an average of about 85% of the total pollen rain, contributed largely by Betula and Alnus. Pseudotsuga increases slightly, and Abies and Picea remain fairly steady, having declined slightly from the preceding zone. Pine values are generally lower than in the previous levels.

There is a reduction in non-arboreal pollen, particularly of the bog species, and this is supported by both the sediment record and plant macrofossils. Peat persists to 274 cm depth, whereupon it is replaced by a marl. Between 290 cm and 275 cm, Cyperaceae macrofossils disappear, and palynomorph frequencies of Equisetum, Cyperaceae, and Typha latifolia decrease, suggesting deepening lake levels and a greater development of open water. This conclusion is supported by the presence of Potamogeton achenes and an increase in Chara oogonia. Note that the high percentages of Equisetum spores are suggestive of an aquatic source, since at present relative frequencies in soil samples taken near terrestrial horsetails are much lower (see Table 3, Appendix 2).

Plant macrofossils consist mainly of seeds and fruit scales of Betula species, seeds of Alnus, Pinaceae, and Acer glabrum, conifer needle fragments (especially of Pseudotsuga menziesii) and deciduous leaf fragments which suggests an open lake surrounded by a closed forest dominated by Douglas fir.

Moister conditions are also supported by the increase in Alnus (Hebda, 1979, unpubl.), and cooler conditions would seem to be suggested by the appearance of a number of montane/subalpine/boreal taxa such as Thalictrum, cf Valeriana sitchensis, and Polemonium pulcherrimum. Paxistima myrsinites, a shrub of the wet subzone of the Interior Douglas Fir biogeoclimatic zone, also appears in the pollen record for the first time.

Non-arboreal pollen comprises about 17% of the total pollen rain, ranging from 11% to 21%, until 210 cm (circa 4100 years BP), when it drops to 14%, with a range of 8% to 19%. This is the product of a decline in Poaceae and *Artemisia* values, which had remained fairly constant from the preceding zone. These AP-NAP frequencies are indicative of a closed forest. Hebda (1979) records NAP values between 12 and 20 percent in closed forest in the Hat Creek Valley which compare with soil surface samples collected from the present forest around Phair Lake. There are some differences between modern and fossil assemblages, however. *Alnus* and *Betula* would appear to be over-represented in the lake samples and *Pseudotsuga* and *Pinus* are under-represented, largely because the former taxa are lake-edge species, occur along the input stream, and thus deposit more of their pollen directly into the water. This suggests that lower *Pinus* frequencies in this zone are an artifact of increased inputs of local pollen types, as evidenced by the reciprocal nature of pine and alder pollen frequencies.

However, *Pinus* influx values are also lower. Influx values in general range from 130 grains per cm^2 per year in the loose upper sediments, to 5480 grains per cm^2 per year at 80 cm (circa 1540 years BP). This peak is a product of increases in the influx of all species, indicating some sort of depositional event. A lower peak at 140 cm (around 2400 years BP) is comprised only of *Alnus* and *Betula*, and therefore reflects some local event which either increased the extent of these species or increased erosion of the lake shores on which they occur (the latter is not suggested by the sediments). Total influx values in this zone are lower than in the preceding zone. Heusser and Florer (1973), working in western Washington, found a reduction in influx values related to development of closed forest conditions, when this forest was dominated by a relatively poor pollen producing species, comparable to *Pseudotsuga menziesii* at Phair Lake.

The sediment change at 106 cm, from lacustrine marl to gyttja (at 1985 ± 145 years BP) is not accompanied by any change in pollen or plant macrofossils. The only change in this zone occurs in the upper 25 cm, where there is a decline in arboreal pollen and increase in non-arboreal pollen suggestive of disturbance of the forest cover.

Chilhil Lake

Zones CL-1 and CLP-1 occur below 330 cm, or about 7040 years BP. The pollen zone is characterized by low arboreal pollen values (averaging 63.5%, and ranging from 56% to 68%), and high non-arboreal pollen percentages (an average of 36.5%, and ranging from 32 to 43%).

Pine values are particularly low (generally between 30 and 48%), as are percentages of *Pseudotsuga* and *Picea*. Uncommon pollen types which first appear in this zone are *Acer glabrum* and *Tsuga heterophylla*. The appearance of hemlock pollen (ca. 7600 years BP) probably reflects its establishment in the Coast Mountains to the west of Phair Lake, rather than locally.

The non-arboreal fraction is comprised largely of "prairie" species, and the percentages of Poaceae (which increases from approximately 5% at the bottom to about 15% at the top of the zone) are typical of prairie vegetation (Webb and McAndrews 1976; McAndrews and Wright 1969). Other species found in relatively large numbers in this zone are Chenopodiaceae (which reaches a maximum of 19%), Tubuliflorae, Rumex, Brassicaceae, Pteridium aquilinum. Polypodiaceae, Selaginella wallacei, and Artemisia.

It is possible that this assemblage represents open "grassland", on the basis of greater than 40% NAP, particularly Poaceae, Artemisia, Tubuliflorae and Liguliflorae, and less than 40% Pinus in the surface samples. However, the composition of the NAP in the Chilhil sediments is quite different, and is also unlike any of the surface samples collected from the vicinity of the lake (see Table 4, Appendix 2), including samples from open pastureland and mudflat areas.

Instead this assemblage seems to represent species of prairie lakes subject to fluctuations in level and drying out in summer. This is supported by the macrofossil record, which is dominated by what are termed "drawdown species", weedy annuals of low lake levels which colonize "mud exposed during droughts" (Birks, 1973, p. 180). The species found include Ranunculus sceleratus and Rumex maritimus var. fueginus, both of which produce light, easily transported seeds, and Chenopodiaceae, the seeds of which are not adapted for floating and which therefore are concentrated in large numbers near the lake shore (Ibid., page 183).

Lake edge species present include lenticular Cyperaceae, trigonous Carex sp., Scirpus cf validus, Scirpus species, ? Scirpus (which resembles Polygonum lapathifolium, a species of fluctuating lake margins, see Plate 1f), Polygonum sp., and Alisma (Plate 1c). The most abundant open water species found are Potamogeton (P. pectinatus and P. cf foliosus) and Zannichellia palustris, both capable of tolerating alkaline waters with a high conductivity (ca. 1250 μmhos; Birks 1973, page 188). Also found are small numbers of Ceratophyllum demersum (Plate 1l), a species of eutrophic lakes, and the achenes of Myriophyllum and Najas flexilis. Najas is a deep water species and is less tolerant of high conductivity, but it is found in such low numbers, though it is a heavy seed producer, as to suggest that it was rare or occured far from the sampling site. Chara, an alga of open water, occurs but is not common. There are also a few seeds of upland species, such as Shepherdia and Rosaceae.

There is in general a good correspondence between the occurence of a species in the macrofossil record and its occurence in the pollen record. The exceptions to this are some of the aquatic species, which are not represented in the pollen.

These data all suggest that at this time (more than 7040 years BP) conditions of drought existed, leading to reduction of water levels. The sampling site was apparently much closer to the shore. Most of the aquatic species found

PLATE 1

FOSSIL SEEDS AND FRUITS FROM LAKE SEDIMENTS

All scales in mm.

A. *Potamogeton pectinatus* L. achene. Chilhil Lake, 340-345 cm.

B. *Potamogeton* sp. achene. Chilhil Lake, 340-345 cm.

C. *Alisma* sp. achene. Chilhil Lake, 330-335 cm.

D. *Ranunculus sceleratus* L. achene. Chilhil Lake, 370-375 cm.

E. *Rumex maritimus* L. calyx. Chilhil Lake, 340-345 cm.

F. *?Scirpus* sp., cf *Polygonum lapathifolium* achene. Chilhil Lake, 340-345 cm.

G. Lenticular Cyperaceae achene. Chilhil Lake, 350-355 cm.

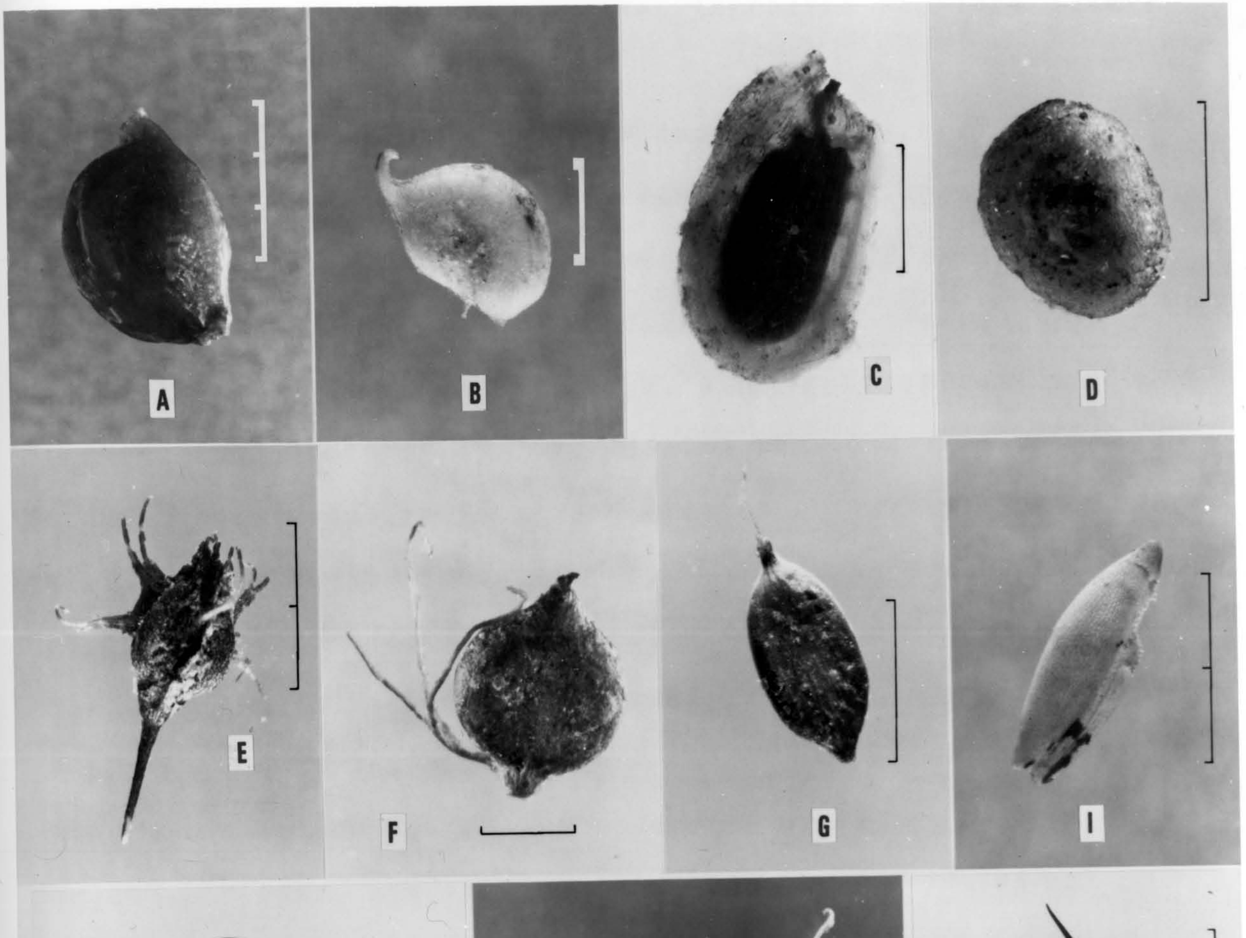
H. Chenopodiaceae seeds. Chilhil Lake, 370-375 cm.

I. *Najas flexilis* (Willd.) Rost. and Schmidt achene. Chilhil lake 370-375 cm.

J. *Zannichellia palustris* L. achene. Chilhil Lake, 350-355 cm.

K. *Myriophyllum* sp. nutlet. Chilhil Lake 340-345 cm.

L. *Ceratophyllum demersum* L. fruit. Chilhil Lake, 345 cm.


A
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C
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G
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K

are tolerant of high conductivity or eutrophic conditions, as would occur if evaporation rates increased and lake levels dropped.

There is a small but regular amount of charcoal and carbonized seed found in the sediments of this zone, which suggests that during the dry summers fire would sweep along the shorelines. Fire frequency might explain the relatively high values of <u>Pteridium aquilinum</u>, a heliophyte which is fire adapted (Rymer 1976). It is also possible that the peak in <u>Pteridium</u> is due to increased erosion of surrounding slopes, related to increased amounts of open ground as produced by drought or fire. That any increase in erosion is not due to increased precipitation is indicated by the abundance of species of prairie lakes and mudflats.

Pollen influx values are moderate, averaging 2450 grains per cm^2 per year, and ranging from 1850 to 3250 grains per cm^2 per year, comparable to influx values for Manitoba prairies (1000 to 2000 grains; Davis et al 1973, p. 17). The relatively high influx values at the base of the core in clay-gyttja suggest that this basal level, ca 8,000 years BP, may not represent the earliest deposition of sediments. It also suggests that when the lake opened up (that is, by the melting of an ice block buried in the ground moraine), the rest of the valley was already supporting a vegetation cover which included <u>Pinus</u> and <u>Pseudotsuga</u>.

Zone CL-2 extends from 330 cm to 205 cm and zone CLP-2 from 330 to 190 cm. The pollen zone (circa 7040 to 4415 $\pm$ 165 radiocarbon years BP) is characterized by increased relative frequencies of *Pinus*, though values which range from about 34% to a peak of 51% are still fairly low, *Pseudotsuga*, and *Picea*. This results in an increase in overall arboreal pollens to an average of about 76%, ranging from 69% to 86%.

The decline in non-arboreal pollen is due to the disappearance or decline of many of the "prairie" species found in the preceding zone. *Rumex* and Chenopodiaceae drop drastically, except for small peaks between 280 and 290 cm (6100 to 6330 years BP). *Pteridium aquilinum* declines and disappears, and Polypodiaceae, *Selaginella* cf *wallacei*, Brassicaceae, and Tubuliflorae decline. Poaceae and *Artemisia* percentages continue steady until the upper third of the zone, and then decline; Poaceae from 11-17% to about 6%, and *Artemisia* from about 3-8% to 3.5% or less.

Although percentages of Poaceae are still high enough to be classified as "grassland", the generally lower NAP values, which average around 24% are more suggestive of a transition between grass and closed forest (Hebda 1979, unpubl.). The pollen rain resembles that recorded for the western forest border in the Northern Great Plains, with *Artemisia* values of about 5%, Chenopods 1%, and Poaceae about 15% (McAndrews and Wright 1969, pg. 41).

Examination of influx values indicates no real increase in arboreal pollen influx. In fact, total influx values have declined from the preceding zone to about 1680 grains per cm^2 per year. This decline and the increase in tree species percentages is due to a reduction in NAP values. This suggests that there has been no alteration of upland vegetation, but a reduction in the extent of the mudflats with their species, a conclusion supported by the macrofossil evidence.

Macrofossil subzone CLP-2a (330 to 245 cm, or ca. 5300 years BP) contains most of the species found in zone CLP-1, but proportions and abundances are different. In general, there is a reduction in the numbers of the "prairie" and "drawdown" species Zannichellia palustris, Ranunculus sceleratus, Rumex maritimus, and Chenopodiaceae, as well as in lenticular Cyperaceae. Other lake edge and marsh species (Scirpus, Carex and Alisma) remain much the same. Brassicaceae (cf Rorippa, a taxon often found in sedge swamps) appears for the first time. Among aquatics, Potamogeton and Ceratophyllum demersum remain constant, while Najas flexilis increases slightly.

The exception to this occurs between 280 and 285 cm (6100 to 6220 years BP). At this level there is a resurgence of all of the "prairie" and "drawdown" species, especially Chenopodiaceae, though this peak is smaller than that found in zone CLP-1. There is also an increase in Scirpus and Eleocharis, and a decline in Potamogeton and Najas. Above this level there is a decline in all species.

This subzone is suggestive of stabilizing lake levels. Mudflat development is less extensive, except for one brief period when summer droughts reoccur, between 6100 and 6300 years BP. There is little evidence for any marked increase in water level.

Subzone CLP-2b (245 to 190 cm, or 5300 to about 4100 years BP) does contain evidence for higher water levels. This subzone contains very low numbers of Ranunculus, Rumex, *Zannichellia*, Chenopodiaceae, and lenticular Cyperaceae. *Alisma*, *Myriophyllum* and *Ceratophyllum* are absent. What characterizes this subzone, however, is the abundance of *Chara* oogonia and *Najas flexilis* achenes, suggesting water too deep for emergents, stabilized lake levels, and a lower conductivity. The mean preferred conductivity of *Najas* is only 180 μmhos (Birks 1973, p. 188).

Note that this zone corresponds with Birks' (1973) findings in Minnesota, namely that weedy annual species basically disappear and water levels increase after about 5000 years BP.

Since Chilhil Lake lacks both inlet and outlet, this increase in water depth undoubtedly reflects either an increase in precipitation or decrease in rates of evaporation. Cooler conditions are also indicated by the appearance in the pollen record of the montane species *Valeriana* cf *sitchensis* and *Thalictrum*.

Zone CL-3 extends from 205 cm (4415 years BP), and zone CLP-3 from 190 (ca. 4100 years BP), to the surface. The pollen zone is marked by an increase in arboreal pollen, averaging 88% between 205 cm and 40 cm, and 75% above 45 cm. This increase in AP is due mainly to an increase in *Pinus* percentages, which average about 57% throughout this zone (ranging from 45 to 68%). The higher pine values are a product of increased pine influx, which more than doubles from the previous zone. There are also slight increases in *Tsuga heterophylla* and *Pseudotsuga menziesii*, while *Abies* and *Picea* remain constant (the influx of all four species increases). *Alnus*, *Betula* and *Salix* decline in the relative frequency diagram, but their influx values actually remain the same or, in the case of Alnus, increase. However, the large increases in Pinus have the effect of masking this change.

In the non-arboreal pollen, the largest declines are in Poaceae and Artemisia, both of which drop to approximately half of their values in CL-2. All other species are maintained at fairly uniform, low values.

Influx values of NAP, however, have changed little from the preceding zone; the differences between the two zones are traceable largely to the much greater influx of arboreal pollen, indicative of a more productive closed forest. Overall influx is greater, averaging 2675 grains per cm^2 below 45 cm.

Non-arboreal pollen percentages average 16%, comparable to NAP values from Hat Creek Valley surface samples taken from closed forest (20%; Hebda, 1979, unpubl.). These percentages also compare with NAP values in the Chilhil Lake soil surface sample aggregate diagrams (Fig. 19).

The pollen record suggests the development of a closed forest about 4415 years BP, which has remained fairly stable until about 40 cm from the surface (ca. 860 years BP assuming a constant rate of deposition), when Poaceae increases and Pinus percentages decline.

In the macrofossil record, there is an increase in species of shallow eutrophic waters and mudflats in zone CLP-3. Potamogeton species (especially P. pectinatus) increase, and Ceratophyllum and Myriophyllum occur sporadically. Zannichellia palustris reaches its greatest abundance. Scirpus achenes increase along with Ranunculus sceleratus, Rumex maritimus and Chenopodiaceae, though these do not approach the abundance of the first zone. Najas flexilis, the deep water species, all but disappears.

Thus water levels in Chilhil Lake would appear to have dropped, perhaps due to renewed occurence of summer droughts leading to the development of mudflats. However, the fewer numbers of seeds and lower pollen counts of drawdown species, reduced amounts of herbaceous detritus in the gyttja, and abundance of Chara oogonia suggest that water levels are greater than in zone CLP-1. It is also possible that lower water levels reflect not primarily climatic conditions, but a hydrosere and the continued eutrophication of the lake.

An exception to the above trend is a narrow band between 110 and 75 cm (about 2370 to 1615 years BP) in which all species but Najas flexilis and Chara oogonia disappear or or decline greatly. Not only do seeds of Ranunculus sceleratus and Rumex maritimus disappear, and Chenopodiaceae decrease, but the pollen of these species is also absent from these levels. There are also minima in Cyperaceae and Myriophyllum pollen. All this suggests a period of more stable water levels and/or deeper water, a conclusion supported by the change in sediment from gyttja to marly materials, which have been reported as being laid down in the deepest part of a lake (Watts and Bright, 1968).

Above this band, as the sediments return to gyttja, there is a return to species of shallower water. Abundance of macrofossils decreases above 40 cm, probably reflecting the unconsolidated nature of the sediments.

Zone CL-3 seems to reflect increased effectiveness of precipitation, leading to more extensive development of closed forest. This change in precipitation/evaporation begins well before the apparent expansion of the forest, with less-pronounced lake level fluctuations beginning with zone CLP-2, and much deeper lake levels occuring between 190 and 245 cm. This would seem to represent reduced summer evaporation rates, possibly related to lower temperatures, and perhaps an actual increase in precipitation.

In the upper zone, the pollen and macrofossil evidence appear somewhat contradictory. The pollen seems to indicate moister conditions, while the macrofossils indicate shallower lake levels and a return to the development of mudflat conditions. The contradiction may be more apparent than real. Mean annual precipitation may have increased in this period at the same time as summer conditions have once again become more extreme, leading to greater fluctuations in water levels. Or this may in fact represent a hydrosere, eutrophic conditions, and the gradual infilling of the lake as time passes.

4.2 The Molluscan Record

Introduction

There is much less correspondence between molluscan zonation and the pollen zones than exists between the latter and the plant macrofossil zonation. The molluscan zones seem to relate more closely to sediment type.

Phair Lake

Zone PhLM-1, below 275 cm (circa 5650 years BP) is basically sterile as regards molluscs. This is undoubtedly due to the nature of the substrates, a bryophytic peat between 274 cm, and 316 cm, and an apparently rapidly accumulated silty clay below that. The presence of molluscs at 300 to 305 cm depth may represent contamination of the peat by a small section of marl.

Zone PhLM-2 is rich in molluscs, and extends from approximately 275 to 110 cm (about 5650 to 2000 years BP), the extent of the marl. It is divided into three subzones.

The sudden appearance of molluscs in subzone PhLM-2a (275 to 210 cm, or about 4050 years BP) is probably due to their transport in mud on the feet of waterfowl, since all species found are small, flat, of clinging habits and facultatively autogamous (Clarke 1969). The subzone is characterized by relatively low numbers of Pelecypoda and the pulmonate snails Gyraulus deflectus, Helisoma (including H. cf corpulentum) and the occasional Physa species. The pulmonates are typical of permanent eutrophic conditions and rooted aquatic vegetation.

The large numbers of immature individuals found suggests that the mollusc assemblage reflects an actual biocoenose - that is, that the species existed very near the site of deposition. In turn, this suggests the presence of rooted aquatic vegetation near what is now the deepest part of the lake, though there are no aquatic plant macrofossils preserved in the sediments. Pelecypoda are less abundant, perhaps due to the widespread occurrence of vegetation, and there are relatively few whole specimens, suggesting that these were transported somewhat further than the Gastropods before deposition.

Subzone PhLM-2b occurs between about 210 cm and 140-145 cm (around the Bridge River ash horizon, circa 2400 years BP). This subzone is dominated by Pelecypoda, which are represented both by single valves and numerous entire specimens. Gastropods include a wide variety of Pulmonate genera - immature Physa species, Lymneids, Gyraulus deflectus, Helisoma cf corpulentum, and Helisoma species, but none of these are abundant. A Prosobranch, Valvata sincera helicoidea, makes its first appearance in the core in this subzone. While all the Gastropods are characteristic of permanent lakes containing macrophytic vegetation, the presence of this Prosobranch, the low numbers of Pulmonata, and the very large numbers of Pelecypoda suggest deeper water conditions than in the preceding subzone. That eutrophic conditions still prevail in the lake is indicated by the increased species richness and the presence of some species (e.g., Gyraulus) which prefer eutrophic waters. However, as a function of higher lake levels, one might expect reductions in the concentration of dissolved nutrients and in turbidity, and a greater oxygen content. The substrate also appears to be more stable.

In subzone PhLM-2c (about 145 cm to 110 cm depth, or 2400 to 2000 years BP) the proportions of species again change to indicate reduced water levels and/or increased eutrophication. Pelecypoda and Valvata sincera helicoides are still present but much reduced in numbers, particularly the former. Pulmonates increase in abundance and diversity. Lymneids, Helisoma cf corpulentum, Helisoma species and immature Helisoma, and Gyraulus deflectus are again numerous. Physa cf gyrina appears, and P. jennessi skinneri, a species of dense vegetation and shallow water, is consistently present. Helisoma trivolvis, which prefers permanent, eutrophic waters, appears for the first time.

The third zone, PhLM-3 (110 cm to the surface of the sediments) coincides with the development of loose gyttja, and is characterized by an absence of mollusca, except for a band between 25 and 45 cm (ca. 480 to 860 years BP). In this layer, overall numbers are low, but species found include immature Physa, Lymneids, Gyraulus deflectus and Helisoma species. Pelecypoda and Valvata sincera helicoidea dominate, suggesting a brief period of deeper water and more stable substrates. No change in the sedimentary column was noted.

Chilhil Lake

Zone CLM-1, below 215 cm (circa 4640 years BP) is basically sterile, with the exception of a few specimens of Pelecypoda, Lymneidae, Gyraulus deflectus, Helisoma cf corpulentum, Helisoma species and Promenetus found between 350 and 370 cm (about 7670 to 7450 years BP). This assemblage is dominated by pulmonates, mostly species requiring shallow water and dense macrophytic rooted vegetation, as is found at

PLATE 2

MOLLUSCS FROM LAKE SEDIMENTS

All scales in mm.

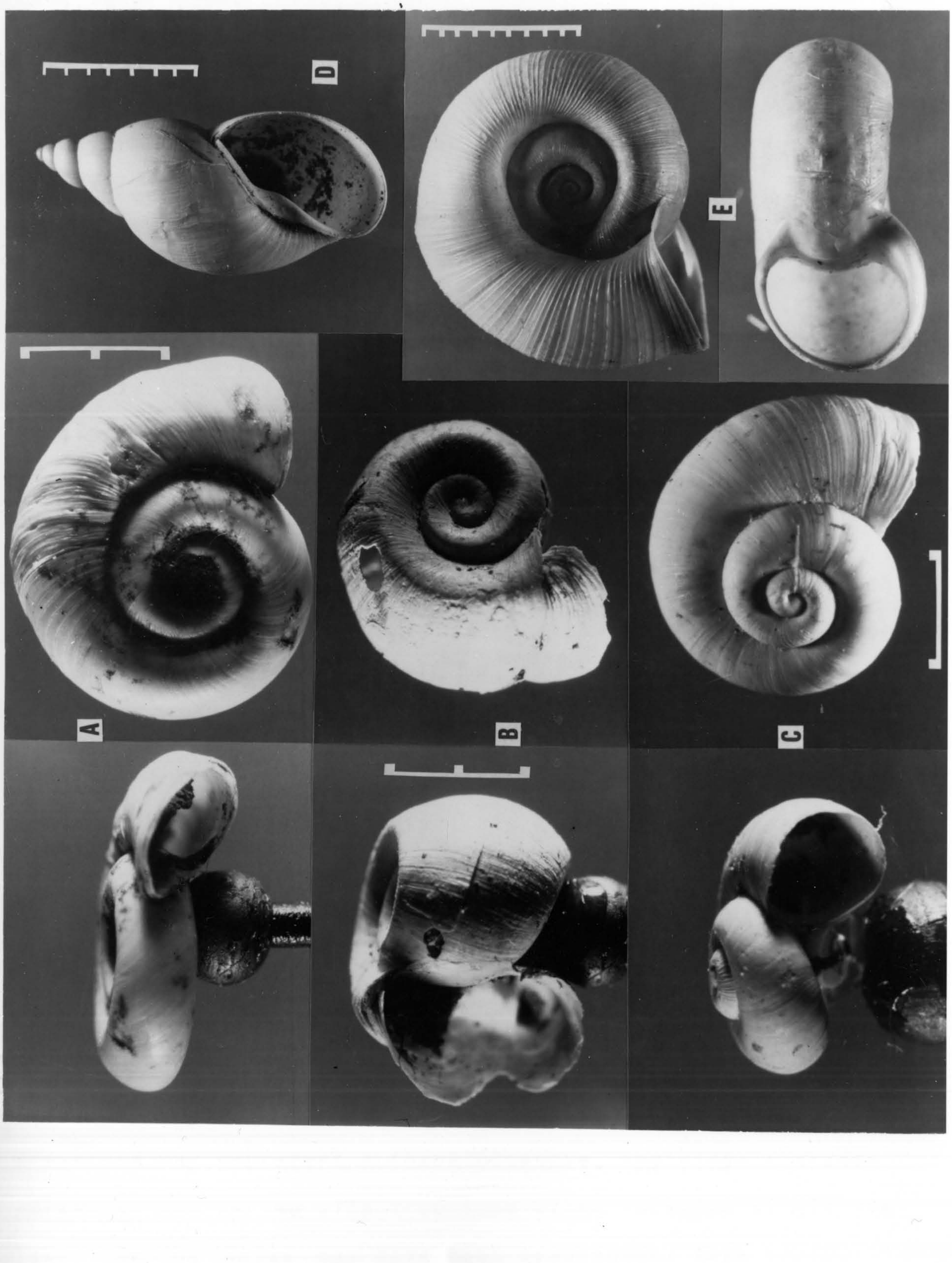
A. *Gyraulus deflectus*. Chilhil Lake, 25-30 cm.

B. *Helisoma* cf *corpulentum*. Chilhil Lake, 140-145 cm.

C. *Valvata sincera helicoidea*. Phair Lake 30 cm.

D. *Stagnicola elodes*. Chilhil Lake, 40-45 cm.

E. *Helisoma trivolvis*. Chilhil Lake, 40-45 cm.


D
E
A
B
C

this level (zone CLP-1).

Why molluscs then disappear for 135 centimeters is unclear. It may be that conditions around 7450 years ago were so severe (i.e., eutrophication was so advanced and water levels so unstable) that the molluscs were actually excluded from the lake. It is more likely that molluscs continued to occur, but not in the vicinity of the coring site.

Zone CLM-2 (215 cm to 0 cm) is characterized by abundant mollusca, and is divided into three subzones. The start of this zone corresponds roughly to the start of pollen zone CL-3, and the middle of plant macrofossil subzone CLP-2b, the Najas flexilis maximum.

Subzone CLM-2a (215 to 105 cm, about 4650 to 2260 years BP) thus begins in an apparent deep water period and continues through a period of apparently shallow water, for the full extent of the gyttja. This subzone contains low numbers of Pelecypoda and the Prosobranch Valvata sincera helicoidea, species of stable deeper water, and numerous pulmonates of shallow, eutrophic waters - Lymneids, Gyraulus deflectus, Promenetus, and moderate numbers of Helisoma species, including H. cf corpulentum and H. trivolvis.

This seems to contradict the plant macrofossil data, but these Pulmonates do not become abundant until about 180 cm depth (about 3880 years BP). In older sediments, the specimens preserved may represent a thanatocoenose, individuals transported to the coring site from some other location within the lake. Or the Najas may have been transported from nearby deeper waters, since the seeds readily float up to 100 meters from the plants (Muenscher 1967; Birks 1973). At any rate, the data does suggest a reduction in lake levels within this subzone, corresponding to the lower portion of zone CLP-3. There is a small peak in the Prosobranch Amnicola (cf limosa), a species indicative of shallow water, rooted vegetation and unstable conditions, above 160 cm (about 3450 years BP).

Subzone CLM-2b extends from about 105 to 60 cm (about 2260 to 1300 years BP) and correlates with the incidence of marl in the sediments, and the evidence for deep water conditions in the plant macrofossil diagram. This increase in depth is confirmed by the molluscan assemblage in which Pelecypoda and Valvata sincera helicoidea reach their maxima. The Pulmonates still occur in the sediments. Lymneids and Promenetus are reduced in numbers, and Gyraulus deflectus and Helisoma species abundant. Their presence indicates that the water levels deepened only slightly, and that conditions were probably eutrophic.

Physa jennessi skinneri appears above 80 cm depth and peaks. This is a species of shallow, eutrophic, well-vegetated areas, suggesting reduced water levels above this depth, though numbers are low and suggestive of a thanatocoenose until about 70 to 75 cm. However, this species is also characteristic of eutrophic waters, and has been known to move to depths of five meters (greater than the present water depth of the site) during warm summers (Clarke 1973; pg. 372). Thus the presence of this species means less than it might except as an indicator of eutrophication.

One might note that whereas the earliest molluscan assemblage contained at least four species of Gastropoda, this assemblage contains at least eight, which is in keeping with Ökland's (1969) finding of an average of 7.2 species of Gastropoda on gyttja in southeastern Norway, and only 3.2 species on clay. The increase may be due to substrate changes, time elapsed for immigration of new species, or may reflect increased enrichment of the lake. (Phair Lake exhibited a similar increase in species numbers from three to at least six, the lower diversity probably a reflection of the smaller size of this lake).

Subzone CLM-2c, 60 to 0 cm, is again gyttja. There is a reduction of all species, with very few Pelecypoda occuring, related perhaps to renewed instability of the substrate and growth of vegetation. This subzone may in fact be a continuation of subzone CLM-2b, since basically the same species are found, and an artifact of the lack of compaction of the sediments.

4.3 Comparison of Phair Lake and Chilhil Lake

The two lakes differ in their origin. Chilhil Lake, which dates from about 8000 years BP, is a kettle lake which explains its morphology (extremely regular), the lack of input and output channels, and the fact that open water seems to have occured at some time subsequent to deglaciation, when the surrounding slopes and valley floor were already vegetated. Birks (1976; p. 396) notes that "ice blocks in terminal moraine may not melt for several thousands of years". The appearance of

Chilhil Lake occurs during a period of apparent maximum drought, and probably warmth (to initiate melting), which ends by about 7040 years BP.

Phair Lake's origin is more puzzling. The presence of a "pothole" which forms the central, deepest portion of the lake is suggestive of a kettle hole, produced by the melting of a remnant block of ice, but the shape of the lake itself suggests that it is a product of a rotational slump of bed-rock material. This may have occured as a result of the under-cutting of the soft shale which makes up the talus slope to the north, and would explain the sharp line of the north shore of the lake.

Phair Lake probably originated between 7250 and 7700 years BP depending on whether maximum or minimum values for the basal C^{14} date are used, and whether the accumulation rate is assumed to be constant within a sediment type or between radiocarbon dates. The actual basal date may be greater, since the lower 35 cm of material consists of a fine blue-grey clay which appears ice-contact in origin. Some authors report an extremely slow rate of accumulation for such sediments (e.g., 1 cm per 190 years; Pennington 1972, p. 88). However, it seems unlikely that these clays have a late glacial origin, because of the macrofossils found and the C^{14} date derived. Instead they would seem to reflect rapid ablation of a high elevation glacier during a period of warmth and drought.

Above about 340 cm this clay contains increasing amounts of black silt, and appears to have accumulated extremely rapidly, possibly leading to a great reduction in water levels and even the infilling of the lake. Around 6940 years BP, the silty clay is abruptly replaced by a layer of ligneous peat, suggestive of a possible hiatus in sedimentation, and the development of terrestrial conditions. Above this point, water levels apparently increase, producing first a moss-sedge peat, and then a moss peat.

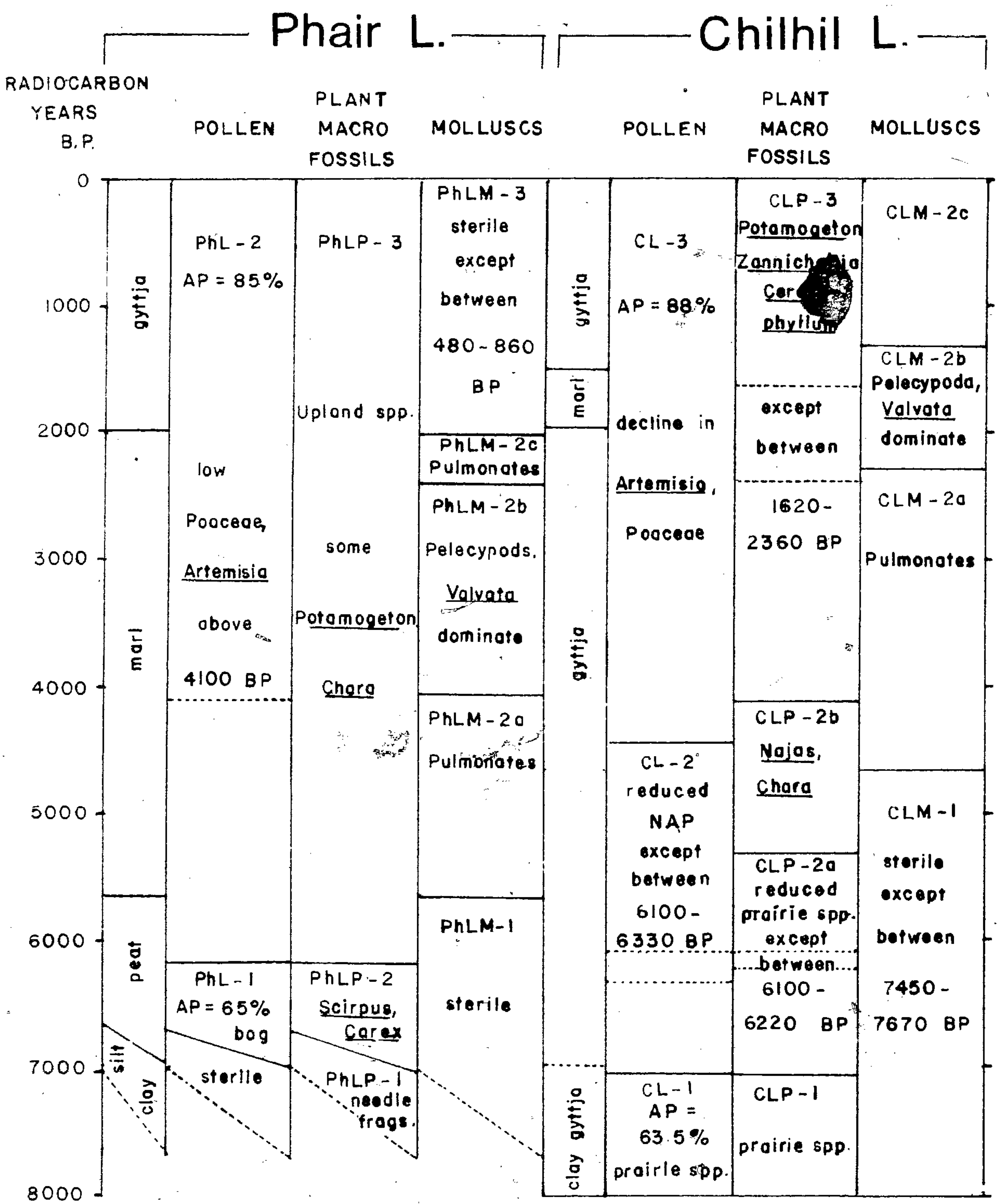
This peat layer corresponds roughly to macrofossil zone CLP-2a in Chilhil Lake (see Fig. 20), which represents a period of increased, and more stable water levels. The apparent increase in water depth at Phair Lake may be due to blockage of the outflow channel or some other local event; its coincidence with like conditions at Chilhil suggests a regional cause.

In fact, the pollen and macrofossil records in Phair Lake indicate increasingly open water above 6180 years BP, while in Chilhil Lake the last expansion of prairie species indicative of drought occurs between about 6100 and 6300 years BP with stable, deeper water levels above this.

Pollen and plant macrofossils at Phair Lake above this level are fairly unchanging, representative of closed Interior Douglas Fir biogeoclimatic zone forest, with the exception of a significant decline in the pollen percentages of Poaceae and *Artemisia* at about 4100 years BP. In Chilhil Lake, *Artemisia* and Poaceae do not decline until about 4415 $\pm$ 165 radiocarbon years BP, with high *Pinus* and *Pseudotsuga* values indicative of the modern forest vegetation appearing above this level.

Both lakes also exhibit some sign of regional disturbance in the upper most sediments. In Phair Lake there is a decrease in *Pinus* and *Pseudotsuga* and an increase in relative

Fig. 20 Comparison of Zonation in Chilhil and Phair Lakes.


Phair L.
Chilhil L.
RADIOCARBON YEARS B.P.
POLLEN
PLANT MACRO FOSSILS
MOLLUSCS
POLLEN
PLANT MACRO FOSSILS
MOLLUSCS
0
1000
2000
3000
4000
5000
6000
7000
8000
gyttja
marl
peat
silt
clay
PhL - 2
AP = 85%
low Poaceae, Artemisia above 4100 BP
PhL - 1
AP = 65%
bog
sterile
PhLP - 3
Upland spp.
some Potamogeton Chara
PhLP - 2
Scirpus, Carex
PhLP - 1
needle frags.
PhLM - 3
sterile except between 480 - 860 BP
PhLM - 2c
Pulmonates
PhLM - 2b
Pelecypods, Valvata dominate
PhLM - 2a
Pulmonates
PhLM - 1
sterile
gyttja
marl
gyttja
clay gyttja
CL - 3
AP = 88%
decline in Artemisia, Poaceae
CL - 2
reduced NAP except between 6100 - 6330 BP
CL - 1
AP = 63.5%
prairie spp.
CLP - 3
Potamogeton
except between 1620 - 2360 BP
CLP - 2b
Najas, Chara
CLP - 2a
reduced prairie spp. except between 6100 - 6220 BP
CLP - 1
prairie spp.
CLM - 2c
CLM - 2b
Pelecypoda, Valvata dominate
CLM - 2a
Pulmonates
CLM - 1
sterile except between 7450 - 7670 BP

frequencies of Betula, Corylus, Spiraea, Fabaceae, and herbaceous Rosaceae in the upper 25 cm (circa 480 years before the present assuming a constant rate of deposition above the upper radiocarbon date). In Chilhil Lake, Poaceae increases and Pinus decreases above 40 cm (about 860 years BP), and Liguliflorae, Fabaceae, Brassicaceae, and Polygonum cf erectum all increase above 15 to 20 cm (320 to 430 years BP). In neither lake is there a sudden influx of charcoal which might explain this as fire-related, nor is there a radiocarbon date available from the uppermost materials, which in both lakes are extremely loose and unlikely to have accumulated at the same rate as the deeper, more compacted sediments.

Thus, in these major trends there is a good agreement between the records of the two lakes. Differences are found when the mollusc record is analysed in relation to inferred water depth. Even so, there is agreement until about 4100 years BP, with both lakes indicating deepening waters to this point. However, above this level, between 4100 and about 2400 years BP, Phair Lake appears to deepen, while Chilhil becomes shallower. There is a brief period of shallow water in Phair Lake between 2400 and 2000 years ago, while Chilhil Lake appears to deepen over a comparable period (circa 2400 to 1600-1300 years BP). Above these levels Chilhil again becomes shallower. Data from Phair lake is not clear. While some authors report gyttja deposited in shallower water than marl (Watts and Bright, 1968), the opposite has also been reported and may be true of this smaller lake.

4.4 Comparison with other sites

A number of recent informally-zoned palynological analyses from British Columbia, and northwestern North America have provided evidence for warmer drier conditions beginning fairly early in the postglacial, and prevailing until about the level of the Mazama ash (see Fig. 21).

The data from Chilhil Lake seems to correspond with a number of these findings. Mathewes and Rouse (1975), working on a core from Pinecrest Lake near Yale, B.C., which is near the transition between Coastal Western Hemlock and Interior Douglas Fir zones, found evidence for warmer conditions beginning around 10,400 years BP, peaking around 8620 ± 135 years BP, and ceasing just prior to the Mazama ash fall. In Chilhil Lake, maximum conditions of drought and warmth occured between about 8000 years BP (the bottom of the core) and 7040 years BP, with relatively dry conditions persisting to about 6100 years ago. Phair Lake is less clearcut as regards conditions prior to 7000 years ago, but also indicates drier conditions persisting until about 6180 years BP.

Alley (1976), working on the Kelowna Bog in the Okanagan of B.C., found evidence for an increase in aridity between 8400 and 6600 years BP, as indicated by low AP values, and increases in Artemisia, Chenopodiaceae, Cyperaceae, Poaceae, and Typha species (species which are abundant in zone CL-1 of Chilhil Lake). He found that marsh species decline and arboreal pollen increased above 6600 years BP, with modern vegetation arriving circa 4500 years ago.

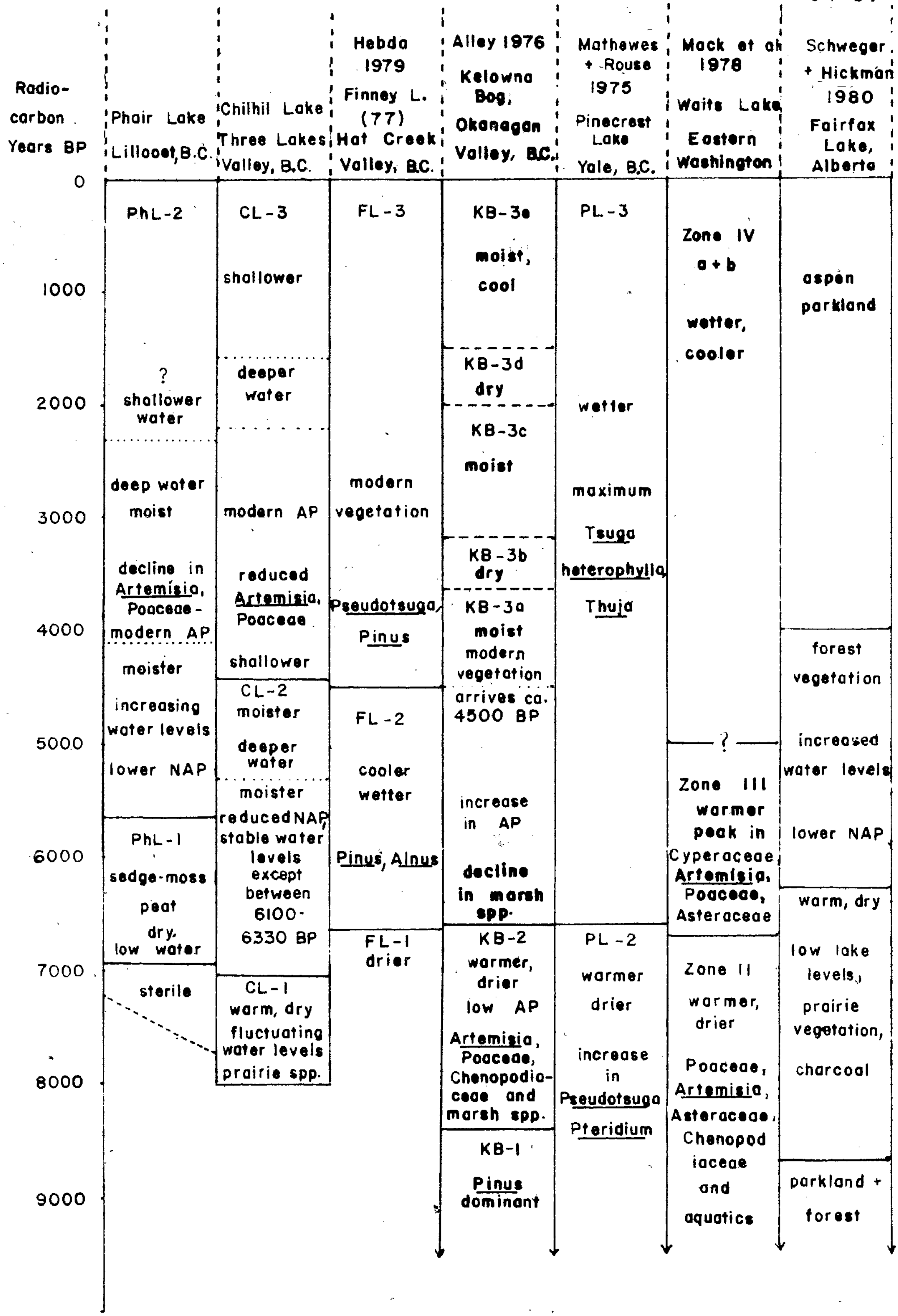
These conclusions are similar to those contained in an unpublished report by Hebda (1979) from the Hat Creek Valley, which is near the study site of this paper. Here, the period of maximal warmth and drought occurs below the Mazama ash, with cooler and moister conditions prevailing from just below the ash to about 4500 years BP, when modern vegetation becomes established. These dates are very similar to those derived at Phair and Chilhil Lakes, where Poaceae and Artemisia levels finally drop and modern assemblages appear about 4100 years BP in the former and 4400 years BP in the latter.

All in all, the lakes examined in this study produced results which correspond fairly well with data from a number of other sites. Most of these are recent studies, with good radiocarbon dating, and informal schemes of zonation which do not attempt to superimpose classical Holocene divisions on the pollen data. Most of the relevant studies come from the northwest, but there are several from more eastern sites which have produced similar results.

Schweger and Hickman (1980) note a maximum in warmth and drought in central and eastern Alberta between 8700 and 6300 years BP, marked by low lake levels and increased fire frequency, with increasing water levels occuring between 6000 and 4000 years BP.

And even farther to the east, Craig (1972) working in northeastern Minnesota, dated the major period of prairie advance as occuring between 8300 and 6500 years ago, with a peak at 7000 years BP. He found that moister conditions

Fig. 21 Summary of inferred climatic changes during the Holocene from sites in Washington and British Columbia.


Radio-carbon Years BP
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
Phair Lake Lillooet, B.C.
PhL-2
?
shallower water
deep water moist
decline in Artemisia, Poaceae - modern AP
moister
increasing water levels
lower NAP
PhL-1
sedge-moss peat
dry, low water
sterile
Chilhil Lake Three Lakes Valley, B.C.
CL-3
shallower
deeper water
modern AP
reduced Artemisia, Poaceae
shallower
CL-2
moister
deeper water
moister
reduced NAP, stable water levels except between 6100-6330 BP
CL-1
warm, dry
fluctuating water levels
prairie spp.
Hebda 1979
Finney L. (77) Hat Creek Valley, B.C.
FL-3
modern vegetation
Pseudotsuga, Pinus
FL-2
cooler wetter
Pinus, Alnus
FL-1
drier
Alley 1976
Kelowna Bog, Okanagan Valley, B.C.
KB-3e
moist, cool
KB-3d
dry
KB-3c
moist
KB-3b
dry
KB-3a
moist
modern vegetation arrives ca. 4500 BP
increase in AP
decline in marsh spp.
KB-2
warmer, drier
low AP
Artemisia, Poaceae, Chenopodiaceae and marsh spp.
KB-1
Pinus dominant
Mathewes + Rouse 1975
Pinecrest Lake Yale, B.C.
PL-3
wetter
maximum Tsuga heterophylla
Thuja
PL-2
warmer drier
increase in Pseudotsuga
Pteridium
Mack et al. 1978
Waits Lake Eastern Washington
Zone IV a + b
wetter, cooler
?
Zone III
warmer
peak in Cyperaceae, Artemisia, Poaceae, Asteraceae
Zone II
warmer, drier
Poaceae, Artemisia, Asteraceae, Chenopodiaceae and aquatics
Schweger + Hickman 1980
Fairfax Lake, Alberta
aspen parkland
forest vegetation
increased water levels
lower NAP
warm, dry
low lake levels,
prairie vegetation,
charcoal
parkland + forest

did not become pronounced until about 3000 years ago.

4.5 Conclusions

The Hypsithermal

The concept of postglacial fluctuation in climate has been a matter for much debate and discussion. Von Post (1930, cited in Sears 1935) first postulated a period of maximum warmth and dryness, or Xerothermic, based on the analysis of northern bogs. This led to a three-fold division of the European postglacial, into a period of gradual climatic amelioration, followed by the Xerothermic, followed by a period of climatic deterioration. Traditionally this Xerothermic was dated between about 8000 and 3000 years ago (Sears 1942), and early palynological workers in North America applied a zonation based on these dates, with some modification. Hansen (1955) described the period of maximum warmth as occuring between 7500 and 3000 years ago in the dry interior of British Columbia, with a peak around the time of the Mazama ash.

Deevey and Flint (1957) modified this system, abandoning the term "Xerothermic" in favour of a formally defined "Hypsithermal Interval", abandoning the earlier term because it implies too much that is unknown and is at best of local application (Ibid., p. 182). To this period were assigned basically the same range of dates that had delimited the Xerothermic.

Evidence for this "universal" period of maximum warmth and drought has been sought in particular and with greatest success from lower latitudes and altitudes, and arid continental areas. Studies from wet coastal areas (e.g., Heusser 1955) did not provide clearcut and unequivocal evidence for a classical Hypsithermal. If such postglacial changes did occur, they "evidently were not of sufficient intensity to cause detectable vegetation shifts" in such regions (Mathewes 1973, p. 2101).

The Lillooet area might be considered an almost ideal location in which to look for evidence of a Hypsithermal. It is continental, in an area of transition between the dry Ponderosa Pine-Bunchgrass and wetter Interior Douglas Fir biogeoclimatic zones, and contains several permanent lakes. While the narrow nature of the biogeoclimatic zones and the wide ecological tolerances of many of the species found will mask many of the shorter term fluctuations, one might expect larger-scale changes to show up in the pollen or macrofossil record.

In fact, there is evidence for a period of greater warmth and drought in the cores from Chilhil and Phair Lakes, during which time lake levels were at a minimum. However, this period does not correspond to the classical Hypsithermal. The driest period seems to end by about 7000 years ago, with fairly dry conditions persisting until about 6100-6200 BP. Above this date, conditions reflect increasing moisture, with "modern" vegetation established by about 4100 to 4400 years BP.

Neoglacials

In addition to a period of greater warmth and drought there have apparently been several periods of renewed alpine glaciation during the Holocene, or neoglacials (Ryder 1978). Many of the climatic fluctuations which produced these neoglacials were "of such short duration they did not effect a substantial response in the vegetation" (Heusser 1973; p. 303). One might expect some record of these periods in Phair Lake, if not Chilhil, since it is located at the foot of the high Coast Mountains and is fed by a stream which apparently descends from high elevations.

Ryder (1978) describes three main neoglacials in the vicinity of Lillooet, occuring between about 5800 to 4900 years BP, 3300 to 2300 years BP, and 1000 years ago to the present, with local glacier development greatest within the last 300 years.

The neoglacials are not recorded in the pollen diagrams of either lake, but may be reflected in changes in water level. The deepening water levels in Phair Lake between about 6180 years BP and 5650 years BP (when the peat disappears) suggest moister conditions which might be associated with the first neoglacial (note that Alley, 1976, reports that neoglacials show up as moister conditions).

The deeper water in this lake between 4100 and 2300 years BP seems to overlap with the second neoglacial. There is no evidence of moister conditions in the upper 1000 years or so, and those changes which do occur seem to suggest drier conditions.

Chilhil Lake does not seem to contain evidence of the neoglacials. The development of stable deeper water between 5300 and 4100 years ago overlaps with the first period of alpine glacier re-expansion, but does not fully correspond to it and in fact largely precedes it. Water levels are lower between 4100 and 2300 years BP, indicating drier conditions during the second neoglacial, and higher between 2300 and about 1600-1300 years BP when there was no glacier development. Again, the upper 1000 years or so seem to record a drying trend.

Thus Phair Lake levels may reflect short term changes in regional conditions to a greater extent than does Chilhil Lake.

Human Settlement

Native peoples have inhabited the Lillooet area since about 9000 years BP, moving into the region following deglaciation from the Columbia Plateau (Sanger 1970). These people seem to have been largely hunters and gatherers, as represented by the "Lochnore Complex" (Ibid).

These hunters were eventually displaced by the Nesikep tradition, which originated in the interior of British Columbia and which was characterized by a high degree of adaptation to the new environment. They not only practiced a system of hunting and gathering that apparently utilized several biogeoclimatic zones but also utilized salmon resources to a greater extent. The appearance of this tradition has been dated by Sanger (1970) at about 7000 years ago, which coincides with the end of the period of maximum drought as recorded in Chilhil Lake. Radiocarbon dates put forward by Borden (1979) suggest a more recent date for the Nesikep tradition (circa 5635 $\pm$ 190 years BP, GX-408). This coincides with the cessation of peat accumulation in Phair Lake, also indicating moister conditions.

The pollen and macrofossil records of the last 3000 years in this area suggest that conditions have been relatively constant, with only a slight drying trend showing up in Chilhil Lake since about 1600 years BP, and possibly in Phair Lake since about 2400 years BP. The reasons for and effects of this trend are not known but it does not appear to have had a major impact on the environment.

There is no evidence of native activity in the pollen record, mainly because they were not an agricultural people. Turner (cited in Kennedy and Bouchard, 1978; page 42) reports that they did practice burning of hillsides to encourage growth of species such as Amelanchier alnifolia, but since fire is frequent in this area, it is impossible to attribute any particular impact to the native peoples.

White settlement of the area began circa 1858, with the Gold Rush (B.C. Lands Service Bulletin #5, 1968). In the early 1860's ranching and farming were practiced in the Bunchgrass prairie along the middle Fraser River. Deliberate burning was practiced to improve rangelands.

Nonetheless, there is no clearcut sign of this activity in the pollen record, unless one were to reassess the dates determined for the increase in NAP in both Phair Lake (above

25 cm) and Chilhil Lake (above 40, and particularly above 15-20 cm). Assuming a constant rate of deposition, these predate the start of white settlement by several hundred years. However, these sediments are so loose that these materials could conceivably represent only the last hundred years or so.

4.6 Summary

The following points summarize the conclusions of this paper:

1. The pollen and plant macrofossil records correspond and indicate maximum warmth and drouth preceding circa 7000 years BP in Chilhil Lake, and possibly in Phair Lake. Moisture increases above this level, but conditions remain fairly dry until about 6200 years BP. Above this point conditions are moister and possibly cooler. There is no evidence for a classically dated Hypsithermal period.

2. "Modern" vegetation pollen assemblages appear circa 4100 years BP in Phair Lake and 4415 $\pm$ 165 years BP in Chilhil Lake, and persist until the upper centimeters of the cores. The apparent time lag between Phair Lake and Chilhil may be a function of the former's location at lower elevations at the foot of the Coast Mountains, or C^{14} dating error.

3. Molluscan macrofossil assemblages were useful in estimating relative water depths, which correlated more or less closely with the levels suggested by the plant macrofossil remains.

4. There is some correlation between Phair Lake water levels and the occurrence of neoglacial periods, though the last period of ice advance (circa 1000 years BP to the present) does not seem to be reflected in this lake. Water levels in Chilhil Lake do not appear to correlate with neoglaciations - in fact, conditions appear drier during these periods.

5. Conditions have been relatively stable in the last 3000 years. No major changes were observed which might influence settlement patterns or hunting and gathering activities of the native peoples of the area, unless the increase in NAP recorded in the upper sediments of the two lakes reflects actual drought conditions and not disturbance subsequent to white settlement of the area. If this does represent a drier period, it is difficult to see what impact this might have had on the environment and the native peoples - a decrease in water levels particularly during the summer months, an expansion of the Ponderosa Pine-Bunchgrass zone, and increased frequency of fire are possible results.

More important is the apparent correlation between the appearance of the Nesikep tradition in the area, and the development of moister conditions.

APPENDIX 1

SPECIES LISTS FROM THE PHAIR LAKE AND CHILHIL LAKE AREAS

1. CHILHIL LAKE SPECIES LIST

ASPLENIACEAE

Woodsia sp.

CUPRESSACEAE

Juniperus communis L. - common mountain juniper
J. scopulorum Sarg. - Rocky Mountain juniper

PINACEAE

Pseudotsuga menziesii var. *glauca* (Beissner) Franco - Interior Douglas fir

SALICACEAE

Populus tremuloides var. *tremuloides* Michx. - Trembling aspen

BETULACEAE

Betula papyrifera Marsh. - Paper birch

URTICACEAE

Urtica dioica subsp. *gracilis* (Wats.) Hitchc. - Stinging nettle

POLYGONACEAE

Polygonum sp.

CHENOPODIACEAE

Chenopodium capitatum (L.) Asch. - Strawberry blite

CARYOPHYLLACEAE

Cerastium sp. - Chickweed

RANUNCULACEAE

Anemone multifida Poir. - Cliff anemone
Aquilegia sp. - Columbine
Delphinium nuttallianum Pritz. - Nuttall's delphinium
Ranunculus glaberrimus var. *ellipticus* Greene - Sagebrush buttercup
R. cf *sceleratus* var. *multifidus* L. - Celery-leaved buttercup

BERBERIDACEAE

Mahonia aquifolium (Pursh) Nutt. - Shining Oregon Grape.

FUMARIACEAE

Corydalis aurea Willd. - Golden Corydalis

BRASSICACEAE

Arabis cf *holboellii* var. *retrofracta* (Grah.) Rybd. - Holboell's rockcress
Arabis sp.
Descurainia pinnata (Walt.) Britt. - Western tansy mustard
D. richardsonii var. *viscosa* (Rydb.) Peck - Mountain tansy mustard

CRASSULACEAE

Sedum lanceolatum Torr. - Lance-leaved stonecrop

GROSSULARIACEAE

Ribes lacustre (Pers.) Poir. -
Black swamp gooseberry
Ribes sp.

ROSACEAE

Amelanchier alnifolia (Nutt.) Nutt. -
Saskatoonberry
Fragaria virginiana Duchesne - Wild strawberry
Potentilla anserina subsp. *anserina* L. -
Common silverweed
Prunus virginiana L. - Common chokecherry
Rosa cf *acicularis* Lindl. - Prickly rose
Rubus idaeus subsp. *melanolasius* (Dieck) Focke -
American red raspberry
Spiraea betulifolia subsp. *lucida* (Dougl.)
Taylor and MacBryde - Birchleaved spiraea

FABACEAE

Astragalus miser var. *serotinus* (Grey) Barneby -
Weedy milk vetch
Astragalus sp.
Lathyrus ochroleucus Hook. - Cream coloured peavine
Trifolium spp. - Clover

CELASTRACEAE

Paxistima myrsinites (Pursh) Raf. - Myrtle boxwood

ACERACEAE

Acer glabrum var. *douglasii* (Hook.) Dippel -
Rocky Mountain maple.

VIOLACEAE

Viola cf *adunca* subsp. *adunca* Sm. -
Early blue violet

VIOLACEAE (Continued)

V. canadensis subsp. Rydbergii (Greene) House - Canada violet

ELEAGNACEAE

Shepherdia canadensis (L.) Nutt. - Soapberry

HALORAGACEAE

Myriophyllum sp. - Water milfoil

ERICACEAE

Arctostaphylos uva-ursi (L.) Spreng. - Bearberry

PYROLACEAE

Orithilia secunda subsp. secunda (L.) House - One-sided wintergreen

POLEMONIACEAE

Polemonium pulcherrimum Hook. - showy Jacob's ladder

BORAGINACEAE

Buglossoides arvensis (L.) Johnston - Corn gromwell
Lithospermum ruderale Dougl. - Columbia gromwell

CAPRIFOLIACEAE

Linnaea borealis L. - Western twinflower
Symphoricarpos albus (L.) Blake - Common snowberry

ASTERACEAE

Achillea millefolium L. - Yarrow
Cirsium sp. - Thistle
Taraxacum officinale Weber - Dandelion

POTAMOGETONACEAE

Potamogeton sp. - Pondweed

CYPERACEAE

Carex concinnoides Mack. - Northwestern sedge
Carex spp.

POACEAE

Agropyron cf *spicatum* (Pursh) Scrbn. and Smith
Bromus tectorum L. - Cheat grass
Poa pratensis L. - Kentucky bluegrass

LILIACEAE

Allium cernuum Roth - Nodding onion
A. validum *Wats*. - Swamp onion
Allium sp.
Disporum trachycarpum (Wats.) Benth. and Hook. - Wartberry fairy-bell
Streptopus amplexifolius (L.) DC. - Clasping-leaved twisted stalk,

2. PHAIR LAKE SPECIES LIST

ASPLENIACEAE

? Athyrium filix-femina (L.) Roth - Common lady fern

Woodsia cf scopulina D.C. Eat.

EQUISETACEAE

Equisetum arvense L. - Common horsetail

E. hyemale subsp. affine (Engel.) Calder and Taylor - Scouring rush

CUPRESSACEAE

Juniperus communis L. - Common mountain juniper

J. scopulorum Sarg. - Rocky Mt. juniper

Thuja plicata Donn. - Western red cedar

PINACEAE

Pinus ponderosa Dougl. - Ponderosa pine

Pseudotsuga menziesii var. glauca (Beissner) Franco - Interior Douglas fir

SALICACEAE

Populus tremuloides var. tremuloides Michx. - Trembling aspen

Salix spp. - Willow

BETULACEAE

Alnus incana (L.) Moench - Mountain alder

Betula occidentalis var. occidentalis Hook. - Water birch

B. papyrifera Marsh. - Paper birch

URTICACEAE

Urtica dioica subsp. *gracilis* cf var. *lyallii* (Wats.) Hitchc. - Lyall's stinging nettle.

CARYOPHYLLACEAE

Stellaria longipes Goldie - Longstalked starwort.

RANUNCULACEAE

Actaea rubra (AIT·) Willd. - Red baneberry

Aquilegia formosa Fisch. - Sitka columbine

Clematis occidentalis subsp. *Grosserrata* (Rydb.) Taylor and MacBryde - Western blue clematis

BERBERIDACEAE

Mahonia aquifolium (Pursh) Nutt. - Shining Oregon grape

BRASSICACEAE

Arabis holboellii Hornem. - Holboell's rockcress

Capsella bursa-pastoris (L.) Med. - Shepherd's purse

Descurainia pinnata (Walt.) Britt. - Western tansy mustard

SAXIFRAGACEAE

Heuchera cylindrica var. *cylindrica* Dougl. - Roundlead alumroot

GROSSULARIACEAE

Ribes divaricatum Dougl. - Coastal black gooseberry

R. irriguum Dougl. - Iadaho black gooseberry

R. lacustre (Pers.) Poir - Black swamp gooseberry

R. viscossissimum var. *viscosissimum* Pursh - Sticky currant

HYDRANGEACEAE

Philadelphus lewisii Pursh. - Lewis' mock orange

ROSACEAE

Amelanchier alnifolia (Nutt.) - Saskatoonberry
Crataegus douglasii var. *douglasii* - Black hawthorn
Fragaria virginiana Duchesne - Wild strawberry
F. virginiana subsp. *glauca* (Wats.) Staudt - Blue-leaved wild strawberry
Potentilla sp. - Cinquefoil
Prunus virginiana L. - Chokecherry
Rosa acicularis subsp. *sayi* (Schwein.) Lewis - Prickly rose
R. cf *nutkana* Presl. - Nootka rose
Rubus idaeus subsp. *melanolasius* (Dieck) Focke - American red raspberry
R. leucodermis var. *leucodermis* Dougl. - Black raspberry
R. parviflorus subsp. *parviflorus* Nutt. - Western thimbleberry
Spiraea betulifolia subsp. *lucida* (Dougl.) Taylor and MacBryde - Birch-leaved spiraea

FABACEAE

Astragalus miser Dougl. - Weedy milk vetch
Medicago sp. - Medic
Trifolium repens L. - White clover

ACERACEAE

Acer glabrum var. *douglasii* (Hook.) Dippel - Rocky Mt. maple

VIOLACEAE

Viola adunca Sm. - Early blue violet
Viola sp.

ELEAGNACEAE

Shepherdia canadensis (L.) Nutt. - Soapberry

ONAGRACEAE

Epilobium angustifolium subsp. *circumvagum* Mosq. - Fireweed

ARALIACEAE

Aralia nudicaulis L. - Wild sarsaparilla
Oplopanax horridus (Sm.) Miq. - Devil's club

CORNACEAE

Cornus sericea L. - Red-osier dogwood

PYROLACEAE

Pyrola chlorantha Sw. - Green wintergreen

HYDROPHYLLACEAE

Phacelia hastata subsp. *hastata* Dougl. - Silverlead phacelia

SOLANACEAE

cf *Solanum americanum* var. *nodiflorum* (Jacq.) Edmonds - Black nightshade

SCROPHULARIACEAE

Penstemon fruticosus of var. *scouleri* (Lindl.) Cronq. - Shrubby penstemon

PLANTAGINACEAE

Plantago major L. - Common plantain

RUBIACEAE

Galium sp. - Bedstraw

CAPRIFOLIACEAE

Sambucus racemosa L. - Elderberry

Symphoricarpos albus (L.) Blake - Common snowberry

ASTERACEAE

Arnica cordifolia Hook. - Heart-leaved arnica

Artemisia frigida var. *frigida* Willd. - Fringed or prairie sagebrush

A. cf *ludoviciana* Nutt. - Western mugwort

Aster conspicuus Lindl. - Showy aster

Cirsium sp. - Thistle

Sonchus sp. - Sow-thistle

Taraxacum officinale Weber - Dandelion

Tragopogon sp. - Goatsbeard

CYPERACEAE

Carex rostrata Stokes - Beaked sedge

Carex spp.

POACEAE

Bromus tectorum L. - Cheat grass

Poa pratensis L. - Kentucky bluegrass

Poa sp.

SPARGANIACEAE

Sparganium sp. - Bur-reed

LILIACEAE

Allium validum Wats. - Swamp onion

Disporum trachycarpum (Wats.) Benth. and Hook - Wartberry fairy-bell

Smilacina racemosa (L.) Deaf. - False Solomon's seal

?*Streptopus amplexifolius* (L.) DC. - Clasping-leaved or cucumberroot twistedstalk

ORCHIDACEAE

Corallorhiza striata Lindl. - Striped coral-root

Cypripedium sp. - Lady's slipper

Goodyera oblongifolia Raf. - Western rattlesnake - plantain.

APPENDIX 2

POLLEN DATA FROM SOIL AND MOSS POLSTER SURFACE SAMPLES FROM PHAIR AND CHILHIL LAKES

Processing and analysis of these surface samples are described in the section of the thesis entitled "Methods". Relative frequencies were calculated, based on a sum that included all but the unknown, indeterminable, and aquatic grains (if any). These data are shown in Tables 3 and 4 under the heading "R.F.". Palynomorph concentrations were not determined.

Percent cover data are also shown for Phair Lake, representing vegetation cover in the 1 m by 1 m quadrats from which the surface samples were taken. These data are placed under the heading "% C" in the Table.

TABLE 3. PHAIR LAKE SOIL SURFACE SAMPLES.

* % cover data missing. 'x' indicates presence.

SPECIES	SAMPLE NO. 1.		2.		3.		4.		5.		6.		7.		8.		9.* moss polster	
	RF	%C	RF	%C	RF	%C	RF	%C	RF	%C	RF	%C	RF	%C	RF	%C	RF	%C
Abies	1.2		3.1		2.9		1.5		1.8		2.0		0.4		0.2		0.8	
Picea	3.4		3.1		3.8		2.4		2.2		2.0		0.7		1.3		4.7	
Cupressaceae			0.9		0.7				12.3		0.7		0.2		1.1		0.6	
Pinus	44.3		43.6		44.8		31.8	0.8	36.6		35.3		9.0		17.7		36.2	x
Pinus monticola type			0.2		0.4		0.2		0.2		0.2						0.2	
Pseudotsuga	31.2		23.3		19.2	9.0	14.1	30.0	16.2		7.9	4.5	0.9		9.5		22.9	
Tsuga heterophylla	0.9		1.1		0.9		0.9		1.3		0.9				0.2		0.4	
T. mertensiana	0.7		1.1		0.4		0.2				0.2				0.4		0.2	
Acer glabrum							1.1	2.0		50.0	0.7				1.1		1.0	x
Alnus	2.5		4.0		8.0	15.0	7.7		8.3		2.0		15.8		17.5		13.4	
Betula	3.2		2.7		7.3		36.5		11.8	50.0	38.6		70.1	100.	35.8	100	11.9	
Populus			0.2				0.2		0.4				0.4					
AP	87.4		83.3		88.4		96.7		91.1		90.5		98.4		84.8		92.3	
Caprifoliaceae								30.0									0.2	
Ceanothus																	0.4	
Paxistima myrsinites											0.2							
Salix											0.2				0.4		0.2	
Liliaceae	0.2				0.7				0.7	5.0	0.7				0.9			
Poaceae	7.1	38.0	10.4	30.0	4.4	25.0	1.1	5.0	4.0	8.3	2.6	7.3	0.7		4.2		2.2	x
Cyperaceae	0.9	10.0	0.4		1.3	25.0	0.2	2.0			0.2		0.4		1.8			
Artemisia			0.2		0.7		0.4		0.7		0.4				0.4		0.6	
Tubuliflorae	0.5	0.5	0.7	20.0	1.1	1.0			0.7		0.2							
Liguliflorae	0.9	4.5	0.4	6.8	0.2						0.2				0.2		0.2	
Polygonum			0.4															
Chenopodiaceae	0.5		0.7		0.2				0.4								0.6	
Caryophyllaceae	0.5		0.2	4.8	0.2													
Brassicaceae				4.0													0.2	
Saxifragaceae			0.4				0.2											
Rosaceae					0.7	15.0	0.2	4.5	0.7		2.6	20.0			0.2		0.2	x
Fabaceae		5.0	0.2		0.2		0.2								0.2		0.2	
Aralia nudicaulis												30.0						
cf *Oplopanax*													0.2	4.0				
Mahonia aquifolium										40.0								
Rumex acetosella									0.2					2.0				
Galium															1.8	6.0		
Epilobium																		
Plantago									0.2									
Equisetum			0.4		0.4	1.0									1.3	7.5		
Cryptogramma	0.5																	
Lycopodium					0.2													
Selaginella	0.5										0.2						0.8	
Polypodiaceae			0.2		0.2		0.2					0.5			0.9		0.4	x
Unknown	0.5		0.2						0.2		0.4				0.2		0.4	
Indeterminable			1.6		1.1		0.7		1.0		1.5		1.1		2.4		1.2	

TABLE 4. CHILHIL LAKE SOIL SURFACE SAMPLES.

PALYNOMORPH RELATIVE FREQUENCIES, IN %.

SPECIES	SAMPLE NO. AND DESCRIPTION								
	treed pasture 1.	treed pasture 2.	Douglas Fir forest 3.	Douglas Fir forest 4.	Douglas Fir forest 5.	mudflat 6.	pasture 7.	moss polster (forest) 8.	moss polster (pasture) 9.
Abies	2.6	2.2	3.1	2.9	2.4	1.1	0.9	2.6	2.4
Picea	3.1	6.9	3.3	4.7	4.0	2.9	2.6	4.3	5.2
Cupressaceae	1.5	0.7	2.4	0.2	0.2	0.9	0.4	1.1	0.4
Pinus	57.7	61.6	46.2	52.3	56.2	31.0	41.8	51.4	64.5
P. monticola type		0.4	0.2			0.2	0.2	0.2	
Pseudotsuga	12.8	4.6	28.1	31.3	26.8	4.9	10.8	20.0	19.6
Tsuga heterophylla	0.7	0.2	0.7	0.9	0.4	0.9	0.9	0.6	0.6
T. mertensiana	0.7	0.2	0.7	0.4	0.4	0.2	0.2	0.2	0.2
Alnus	2.0	1.3	4.4	2.0	2.2	3.1	2.2	2.8	2.8
Betula	0.7	0.2	1.5	1.3	0.4	0.2	0.4	0.4	0.2
Populus	0.2						0.2		0.2
AP	82.0	78.3	90.6	96.0	93.0	45.4	60.6	83.6	96.1
Ceanothus		0.2					0.2		
Ericaceae					0.2				
Shepherdia canadense					0.2				
Paxistima myrsinites				0.2					
Liliaceae								1.7	
Poaceae	8.4	10.8	4.0	1.8	3.5	30.3	6.6	7.3	1.8
Cyperaceae	1.3	2.0				0.9	0.7		
Artemisia	0.7		0.7		0.2	0.2	0.2	0.2	0.2
Tubuliflorae	0.7	0.4		0.2		3.6	0.7		
Liguliflorae	2.0	2.2	0.2		0.4	2.0	20.9		0.4
Polygonum cf *erectum*						3.6		0.2	
Polygonum		1.0				0.7			
Rumex		0.7				1.8			
Chenopodiaceae	0.2	0.4		0.2		0.7	1.5		
Caryophyllaceae	0.2				0.2			0.2	0.2
Brassicaceae	0.2	0.4	0.2	0.2	0.2	7.1	2.9		
Ranunculaceae		0.2			0.2	0.2	2.2		0.2
Saxifragaceae	0.2		0.2			0.2	0.2		
Fumariaceae		0.2							
Rosaceae	0.4		0.2			0.7	0.2	0.2	0.2
Fabaceae	0.9	0.9			0.2	1.1	0.9	0.4	0.2
Apiaceae						0.2	0.4		
cf *Urtica*			0.2						
Cryptogramma							0.2		
Lycopodium			0.2		0.9			0.2	
Polypodiaceae		0.2	0.4					2.6	
Selaginella	0.2		1.3						
Myriophyllum						0.2			
Unknown	0.4	0.4	0.2			0.7	0.2	1.5	0.2
Indeterminable	2.2	1.3	1.5	1.3	0.7	1.3	1.5	1.3	0.6

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