LATE QUATERNARY GEOCHRONOLOGY AND PALAEOECOLOGY OF THE UPPER PEACE RIVER DISTRICT, CANADA

by

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M.A. Simon Fraser University 1977

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Late Quaternary Geochronology and Palaeoecology
of the Upper Peace River District, Canada

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ABSTRACT

Pollen percentage and influx analyses and radiometric dating of sediment cores from three lakes in the Peace River district of northeastern British Columbia and northwestern Alberta were used to investigate the regional Late Quaternary geochronology and palaeoecology. Microfossil and macrofossil analyses of a basal core segment from Boone Lake showed that two ^{14}C ages greater than 12,000 years B.P. were spuriously old due to Cretaceous age organic contamination. The sedimentary record began in Boone Lake about 12,000 years B.P. during deglaciation, and sedges dominated a diverse aquatic and upland vegetation close to the receding ice. A poplar - willow - sage - grass - sedge zone occurred probably prior to 11,600 years B.P., indicating a humanly habitable 'Ice-free Corridor' in the Saddle Hills. A major poplar decline took place at about 10,800 years B.P., probably because of increasing competition from conifers. The forest was similar to modern boreal coniferous forest with more abundant shrubs and herbs. It is considered unlikely that spruce could have migrated from the central prairies to Beringia by 11,500 years B.P. without becoming established in the Peace River area prior to 10,400 years B.P. The regional pine presence at 10,400 years B.P. sets a minimum age for the withdrawal of Glacial Lake Peace to the Indian Creek Stage, and for the cessation of regional periglacial activity. A possible minor climatic regression took place about 10,000 years B.P. Tree birch became an important forest element between 8700 and 8200 years B.P., followed by a pine peak at 7400 years B.P. which is interpreted as the Hypsithermal maximum. No significant expansion of the Peace River grasslands took place during the Hypsithermal. A trend to wetter conditions began around 7400 years B.P., with the establishment of some permanent ponds by about 5100 years B.P. A minor spruce decline and alder increase has taken place in the last 3400 years. The application of a non-parametric statistical technique is proposed as a test for randomness of distribution of uncommon pollen types.

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especially to acknowledge my committee members, Dr. Knut Fladmark for his encouragement and valuable questions, and Dr. W.H. Mathews for his discussions and geological advice regarding suitable coring sites. Above all, I thank Dr. Rolf Mathewes for his advice, encouragement, support, and for accepting a neophyte into his lab.

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INTRODUCTION

This research provides a Late Quaternary palaeoenvironmental reconstruction for the upper Peace River district of Alberta and British Columbia, and relates this reconstruction to problems in human prehistory, palaeobotany, Pleistocene geology, and palaeoclimatology.

The effect of the natural environment on the economic and social structure of culture has been amply demonstrated by the cultural ecological theory of Julian Steward (1955). The study of cultural systems requires that the environment be included as a fundamental component of the analysis (Clarke 1971:101-130). Indeed, cultural materialism can be argued to be the most appropriate and fruitful theoretical strategy for archaeology (Price 1982). Modern archaeology thus requires that past environments be as well documented as past cultures.

The natural environment within which a culture exists can be roughly divided into geological, climatic, floral and faunal components (Clarke 1971:124). Although the underlying importance of geology and climate cannot be minimized, it is the living system which most directly affects human culture. Plants are the first trophic level of a food chain. It follows that past floristic and vegetation patterns are fundamentally important to archaeological interpretation. Pollen analysis is the principal method of reconstructing Quaternary environments (Birks and Birks 1980).

The importance of environmental knowledge to archaeological interpretation is most clear-cut in the determination of whether a land surface was available for human occupation. Part A of this thesis contributes to the study of the hypothesized 'Ice-free Corridor', a route by which man might have migrated into the unglaciated southern portion of North America during or just after the Late Wisconsinan glacial period. This research has been undertaken by radiometric dating and pollen analyses of sediment cores from Boone and Spring Lakes, from near the limits of the Laurentide and Cordilleran ice advances in the Peace River district. These cores provide a minimal age for local deglaciation and a record of Late Wisconsinan - early postglacial vegetation.

Part B of this thesis provides a regional postglacial vegetation sequence from the sedimentary records of Boone Lake, Spring Lake, and Fiddler's Pond. It discusses the floristic, vegetative, and palaeoclimatic significance of these pollen sequences.

The Pleistocene - Holocene boundary has been formally placed at 10,000 years B.P. by the 8th INQUA Congress at Paris, 1969 (Hafsten 1970). In this study the term 'Late Wisconsinan', or 'late glacial' is used to define the latest period when most of the study area was ice-covered. 'Postglacial' denotes the period after major ice ablation in the study area.

The convention followed in this thesis for the use of common and Latin names for plant taxa is described below. Common specific names for trees and large shrubs, and common plant families or genera are enclosed in parentheses after the first Latin citation of that taxon, in each part. Thereafter, common names are normally used. However, the Latin name is used when reference is made to a table or figure in which the taxon is designated by its Latin name, or where the common name is not sufficiently precise. Uncommon shrubs, and all herbs and aquatic plants are always named in Latin. Both Latin and common names follow Taylor and MacBryde (1977).

A. Late Wisconsinan - Early Postglacial Transition

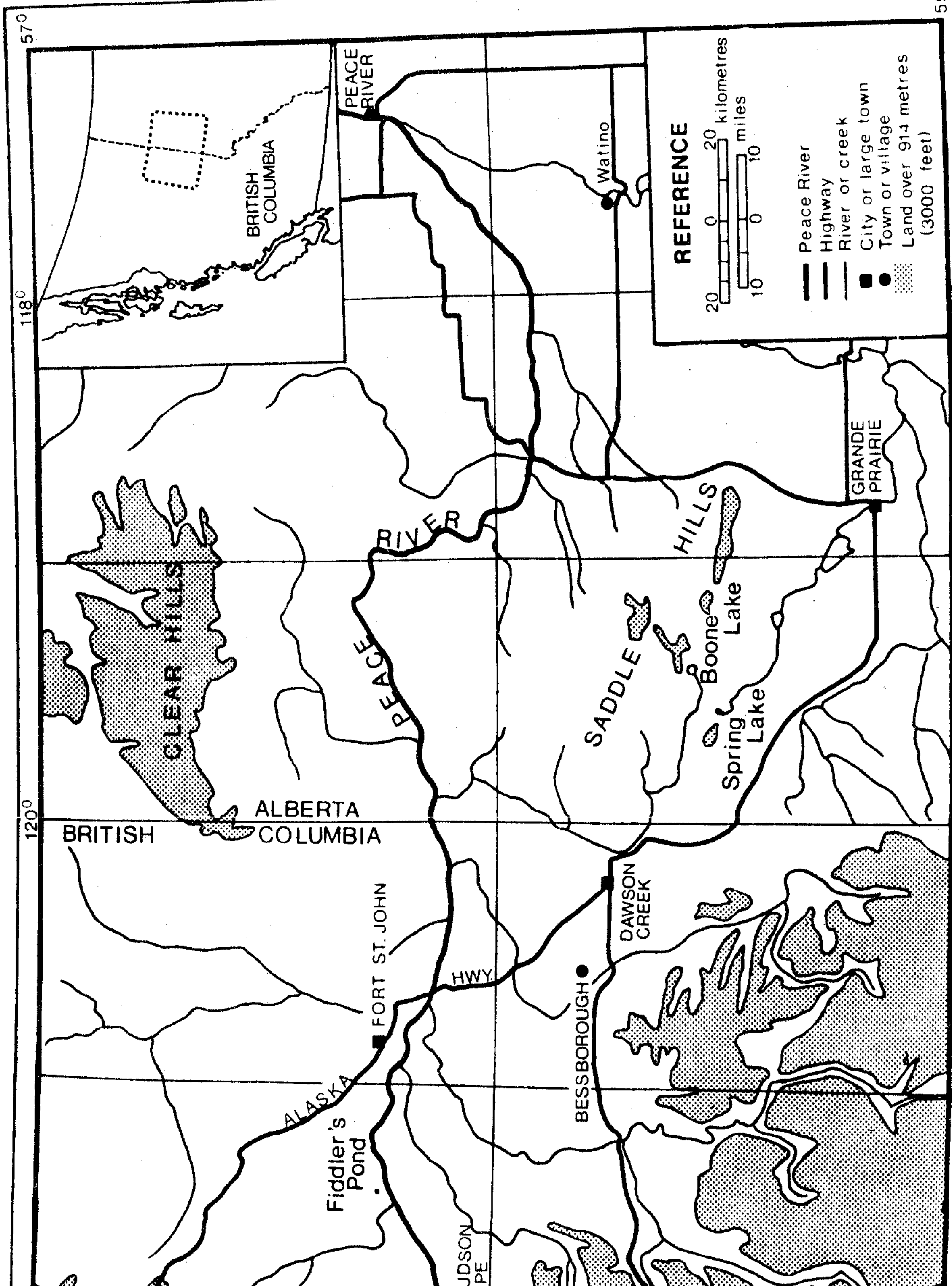
The timing of and environment within an hypothesized Late Wisconsinan 'Ice-free Corridor' between the Laurentide and Cordilleran ice masses has been important to archaeologists considering the early arrival of man into the Americas since it was first proposed by Johnston (1933). Griffin (1960), Haynes(1964,1971,1980) and Martin (1973) have relied on the existence of an Ice-free Corridor prior to 11,500 years B.P. to explain the appearance of the Clovis culture in unglaciated southern North America by 11,500 years B.P. Reeves (1973) has argued that geological evidence indicates that the corridor has been open for the last 55,000 years, with a local blockage between 18,000 and 20,000 years B.P. On the other hand, Bryan (1969) argued that the corridor was blocked until at least 9000 years B.P. Fladmark (1979,1981) has concluded that the corridor was likely blocked or uninhabitable between the Peace River and the Yukon during the Late Wisconsinan.

The possibility of use of a Pacific Coast migration route proposed by Heusser (1960) and Fladmark (1979,1981) has been strengthened by the recent demonstration of a refugium on the Queen Charlotte Islands during the height of the Late Wisconsinan glaciation (Mathewes _et_ _al_. 1982,Warner _et_ _al_. 1982).

To botanists studying late Pleistocene and Holocene floristic patterns in northwestern North America, the possible existence of refugial areas and early migration paths in or along the eastern flanks of the Rocky Mountains figures prominently(Bird and Marsh 1973; Halliday and Brown 1943; Hansen 1949a,b, 1950,1952, 1955; Hopkins _et al._ 1981; Hulten 1937; Mulligan 1970, Packer 1980; Packer and Vitt 1974). However, the extent of ice advance and the chronology of retreat in this area are still uncertain (Bryson _et al_. 1969, Denton and Hughes 1981, Prest 1969, Wilson _et al_. 1958 (see Andrews 1982)), thus hampering archaeological and palaeobiological investigations.

Part A reports the results of pollen analyses, macrofossil analyses, and radiocarbon dating of the late glacial - early postglacial section of sediment cores obtained from two sites in the Saddle Hills in the Peace River district of Alberta and British Columbia (Figure 1), which is within the possible late glacial corridor area. The significance of these data for corridor environments and chronology is discussed.

Figure 1. Map of the upper Peace River district.


57°
55°
118°
120°
122°
REFERENCE
20 10 0 20 kilometres
10 0 10 miles
Peace River
Highway
River or creek
City or large town
Town or village
Land over 914 metres (3000 feet)
PEACE RIVER
Watino
BRITISH COLUMBIA
GRANDE PRAIRIE
SADDLE HILLS
Boone Lake
Spring Lake
CLEAR HILLS
PEACE RIVER
ALBERTA
BRITISH COLUMBIA
DAWSON CREEK
HWY.
FORT ST. JOHN
BESSBOROUGH
ALASKA
Fiddler's Pond
HUDSON HOPE
ROCKY MOUNTAINS

I. Regional Bedrock and Surficial Geology

The Quaternary deposits of the Interior Plains of northeastern British Columbia and Alberta are underlain by Upper Cretaceous strata (McCrassan and Glaister 1964:2). The bedrock geology of the Saddle Hills area, bounded by 119° and 120° West and 55° and 56° North, has been summarized by Odynsky et al. (1961). The northern two thirds of the area is underlain by shale of the Smoky River formation, while the southern third is underlain by the Wapiti formation sandstone and shales. The Smoky River and Wapiti formations are Upper Cretaceous in age (McCrassan and Glaister 1964:2).

Recent contributions to the Quaternary geology of the Peace River district have been made by Henderson (1959), Jones (1960), Mathews (1963,1971,1978,1980), Odynsky et al. (1961), Reimchen and Rutter (1971), Reimchen (1980), Rutter (1977,1980), St-Onge (1972), Taylor (1960), Westgate et al. (1972), and White et al. (1979).

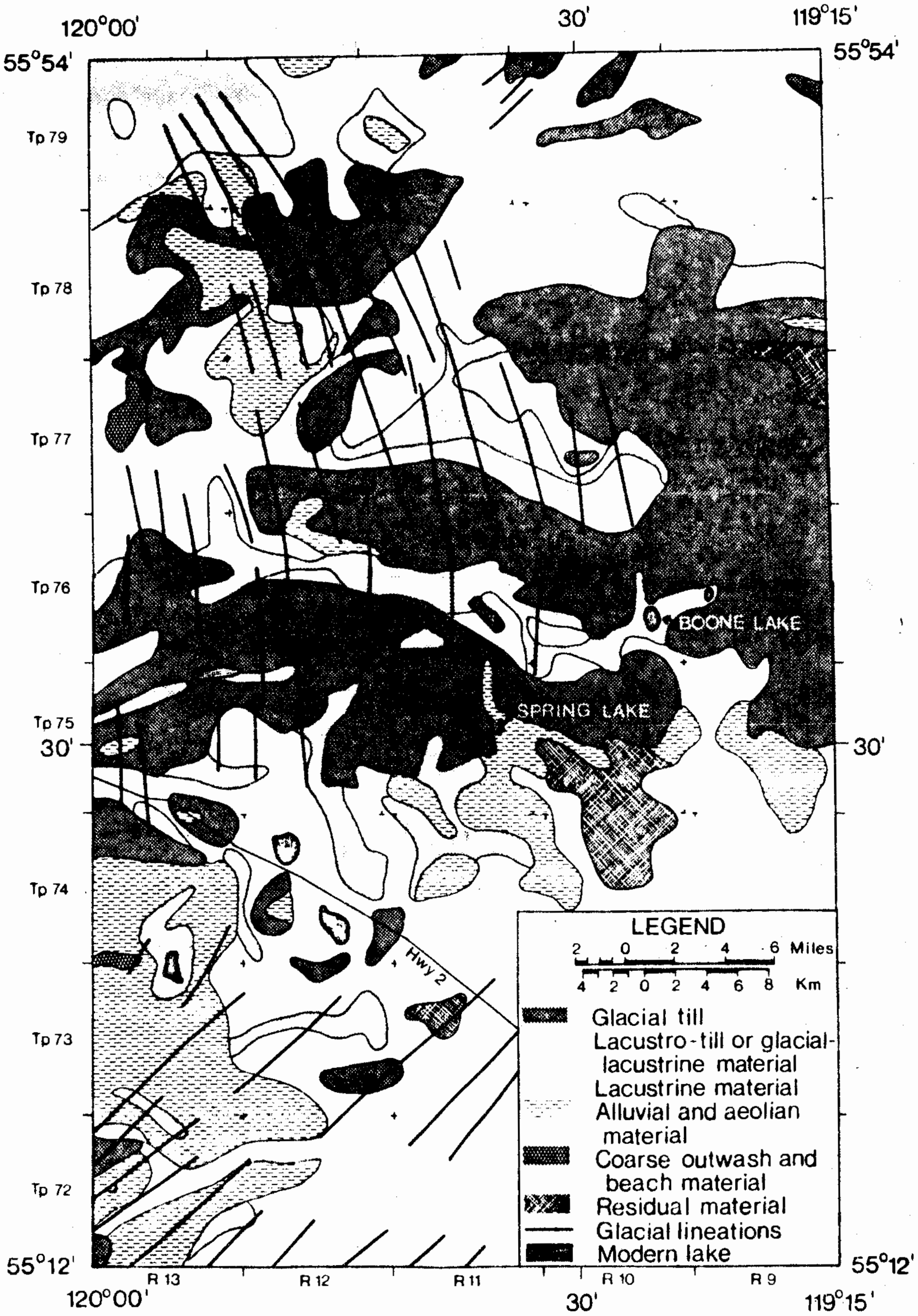
Regional overviews of Late Wisconsinan glaciation and deglaciation in the Peace River area are provided by Mathews (1978,1980) and St-Onge (1972). Mathews has presented evidence of extensive Late Wisconsinan ice advances from Cordilleran and Laurentide sources, and has described recessional phases associated with the development of Glacial Lake Peace pondages and spillways. St-Onge has described the development and drainage of proglacial lakes in northern Alberta farther east of the study area.

The distribution of late Quaternary surficial deposits in the Saddle Hills area is shown in Figure 2, simplified by the author from the Beaverlodge and Blueberry Mountain soil survey of Odynsky _et_ _al_. (1961). Soils developed on residual parent materials are of limited extent. A till occupies a major portion of the central map area. This is described as "...a greyish brown to yellowish brown, sandy clay loam to clay till, that is somewhat stony, has numerous coal flecks and may be largely derived from both the Smoky River and Wapiti formations."(Odynsky _et_ _al_. 1961:25). This till underlies many of the other deposits in the map area. A deposit which lies immediately above the till "...consists of a well sorted, grey to dark greyish brown clay that has few stones,(and) numerous gypsum crystals...."(Odynsky _et_ _al_. 1961:26). This may have been laid down in a glacial lake and has been termed "lacustro-till". It rarely exceeds 771 m (2500 ft) in elevation, and between that elevation and 801 m (2600 ft) in the western portion of Figure 2 it is more variable, such that beds of dark clay may be interbedded with the yellowish brown sandy or stony till-like material. Overlying the lacustro-till in the western map area is a thin till which is yellowish brown and sandy, gravelly or stony. The stones are quartzites and occasional sandstones, suggesting a Cordilleran origin. The material is commonly aligned in parallel northeast - southwest trending low ridges. This material is found predominantly in Townships 74 to 78, Ranges 12 and 13 (Figure 2).

Stone-free clays of apparent postglacial origin occur in the lower basins, usually below 671 m (2200 ft) and in the northwest map area. South of the area shown in Figure 2, near the Wapiti River are sandy and silty materials which have apparently been wind worked, or which show humpy topography possibly resulting from frost action. Gravely outwash or beach material occur in association with tills or lacustrine deposits.

Glacial lineations are clearly visible on aerial photographs of the research area. The lineations in Figure 2 have been transfered by the author from the 1961 aerial photographs 83M 2640', Flight Lines 5505 to 5520. These lineations were likely caused by two ice sources. The lineations trending northeast, and which are located southwest of Highway 2, are interpreted by Mathews (1980) to have resulted from an ice advance out of the Redwillow Valley. The ice flowed over glaciolacustrine sediment apparently as far as Highway 2. The limit of the advance is not marked by a terminal moraine. Northnorthwest-trending lineations are found north of Township 74 and west of Range 9 in Figure 2. Reimchen's (1980) surficial geology map for Dawson Creek, adjacent and to the west of Figure 2, shows parallel lineations in Townships 74 to 76, Ranges 14 and 15, and indicates an ice flow from north to south (Reimchen and Rutter 1971), apparently a Laurentide advance. A terminal moraine does not mark the limit of this southward advance. Evidence of another ice flow is found in lineations trending

Figure 2. Surficial geology of the Saddle Hills area.


120°00'
30'
119°15'
55°54'
55°54'
Tp 79
Tp 78
Tp 77
Tp 76
Tp 75
Tp 74
Tp 73
Tp 72
30'
30'
55°12'
55°12'
R 13
R 12
R 11
R 10
R 9
120°00'
30'
119°15'
BOONE LAKE
SPRING LAKE
Hwy 2
LEGEND
2 0 2 4 6 Miles
4 2 0 2 4 6 8 Km
Glacial till
Lacustro-till or glacial-lacustrine material
Lacustrine material
Alluvial and aeolian material
Coarse outwash and beach material
Residual material
Glacial lineations
Modern lake

northeast in Township 79, Ranges 10 and 11. Mathews (1980) has interpreted the north - south trending lineations in the Saddle Hills and Dawson Creek area and the northeast trending lines in the northern Saddle Hills as representing a Late Wisconsinan Laurentide ice flowing around the Clear Hills, while the lineations to the southwest of Highway 2 represent a Redwillow Valley advance. Clearly, the Laurentide ice must have flowed very close to, or over the Spring Lake and Boone Lake basins.

Deglaciation and early postglacial processes probably account for the aeolian, alluvial and lacustrine deposits.

Glacial Lake Peace, formed during deglaciation (Taylor 1960, St. Onge 1972, Mathews 1963,1971,1978,1980), inundated much of the Peace River district. The highest known level is the Bessborough Phase, defined by a series of shorelines about 830 m (2725 ft) asl near Bessborough, B.C. (Mathews 1978). An allowance for postglacial isostatic rebound (Mathews 1980) places the Bessborough Phase shoreline in the vicinity of Boone Lake at 804m (2637 ft) to 814 m (2670 ft), well below Boone Lake's 871 m (2860 ft) elevation. The Bessborough Phase shoreline in the Spring Lake vicinity would have stood near 807 m (2648 ft) to 819 m (2687 ft), below Spring Lake's present 835 m (2740 ft) elevation. The lacustro-till reported by Odynsky _et al._ (1961) in the Beaverlodge area, distributed below 771 but up to 801 m, could have been deposited by the Bessborough or a lower stage of Glacial Lake Peace.

Ice-related features near Boone Lake and Spring Lake

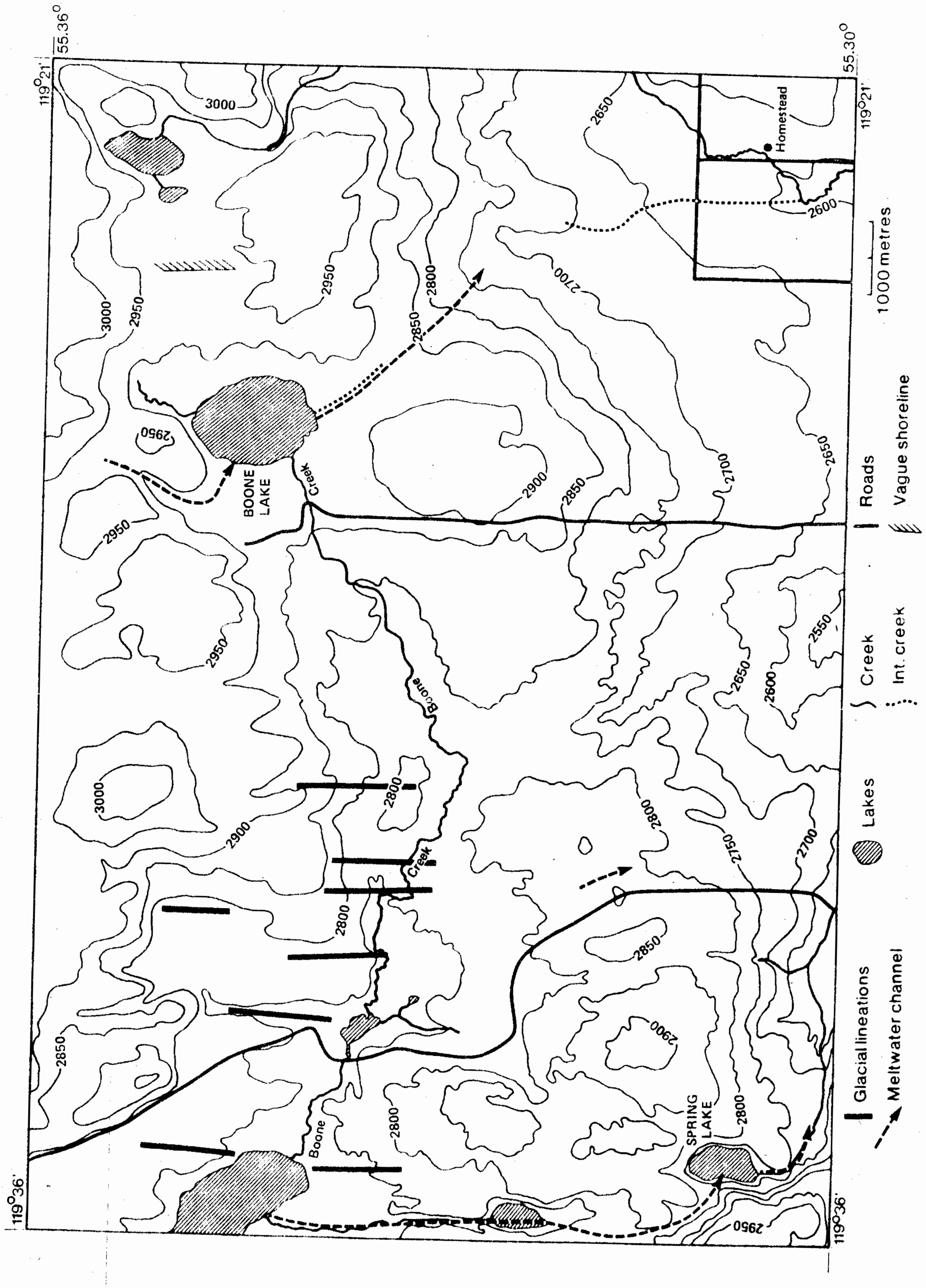
Boone Lake (Figure 3) is the upper pondage of Boone Creek, has minor inflow streams from the north and southeast, and is surrounded by subdued topography (Figure 3). Boone Creek drains to the west, flowing through lacustrine and glaciolacustrine sediments which divide the till to the north and south (Figures 2,3).

Inspection of aerial photographs reveals several lacustrine and fluvial features of probable Late Wisconsinan origin. Elevations of features discussed below are derived from interpolation of contour lines on the Saddle Hills 1:50,000 NTS sheets (83 M/11 West Half) based on 1945 aerial photography.

Boone Lake appears to sit in a basin occupied by a formerly more extensive pondage (Figure 3). An arm of the basin extends 3 km to the northeast of Boone Lake to the adjacent lakes. Another arm seems to extend 4 km southwest along Boone Creek where it is interrupted by glacial lineations. Faint lineations occur to the north of this arm and there are faint lines, possibly lineations, to the south of it. The elevation of this whole basin is as low as 846 m (2775 ft) to the southwest and as high as 892 m (2925 ft) to the northeast. Considering this elevation difference it seems unlikely that the whole basin was inundated contemporaneously.

Mathews has identified a vague shoreline about 1 km east of the lake (White *et al.* 1979). A field check on this feature was

Figure 3. Ice-related features around Boone and Spring Lakes.


119°21'
55.36°
55.30°
119°21'
119°36'
119°36'
3000
2950
2900
2850
2800
2750
2700
2650
2600
2550
BOONE LAKE
SPRING LAKE
Boone Creek
Boone
Creek
Homestead
1000 metres
Glacial lineations
Meltwater channel
Lakes
Creek
Int. creek
Roads
Vague shoreline

done by the author in the fall of 1979. It is a ridge trending north-south, about 15 m wide and standing about 1.5 m above the surrounding land. A game trail and _Pinus contorta_ (lodgepole pine) trees mark the top of the low ridge, which is surrounded on both sides by a _Picea mariana_ (black spruce) forest. A .5 m deep posthole showed a yellow brown sand/silt matrix with few pebbles. The ridge stands about 20 m above the present Boone Lake level.

Several abandoned channels are found near Boone Lake. A vague meltwater channel enters the basin from the northwest (White _et al_. 1979). The channel becomes visible 1 km northwest of Boone Lake. It originates south of a drainage divide at 884 m (2900 ft). North of this divide elevations drop and the terrain is hummocky and irregular. The channel thus apparently originated at an ice margin just northwest of Boone Lake. Another channel leaves the Boone Lake basin to the southeast, and is distinct for 2.5 km. It is presently occupied by an intermittent inflow stream to Boone Lake. A vague continuation of this channel is visible further southwest, presently occupied by an intermittent stream which joins a tributary of Bear Creek near Homestead.

Spring Lake lies 11 km southwest of Boone Lake (Figures 2,3). A distinct meltwater channel connects the Boone Creek drainage to Spring Lake over a present drainage divide, and continues southeast for 1 km along the path of the present drainage of Spring Lake.

These ice-related features show that Laurentide ice advanced at least as far south as the Boone Creek drainage. At some stage, possibly an early stage of retreat, ice blocked Boone Creek. Meltwater, originating from an ice mass 1 to 2 km north, drained into Boone Lake. The shoreline northeast of Boone Lake is likely related to an ice-dammed meltwater pondage which drained through a channel to the southeast. Meltwater also drained southward through Spring Lake, and through at least one short channel between the two lakes.

Boone Lake was chosen as a study site because it stood above the Bessborough stage of Glacial Lake Peace and beyond the late Redwillow Valley advance (W. Mathews personal communication 1978) and because it is accessible by road.

II. Spring Lake and Boone Lake Morphometry and Sediment Lithology

Spring Lake

Spring Lake is 980 m by 478 m, and covers 32 ha. The meltwater channel previously discussed may serve as a conduit for groundwater feeding into Spring Lake. The surficial inflow to Spring Lake is by a short intermittent stream from the north. The outlet of the lake is to the south, by a minor permanent stream.

Beaver dams at present raise the level of the lake by 2 to 3 m. A local informant indicated that the tail of the lake was a hay meadow until inundated by the beaver dams, and drowned spruces above the beaver dam attest to the historic rise in water level.

The shores of the lake are steep, and bathymetry (Bishop 1979) indicates that this profile continues underwater. The lake has a shelf on the south end, a continuation of the former hay meadow, which descends gradually to a depth of 12 to 13 m. The north end of the basin drops sharply, reaching a depth of 20.3 m. Spring Lake is an unusually deep lake in the Peace River area in the author's experience, which is corroborated by other bathymetric studies (Bishop 1979).

Spring Lake exhibits permanent thermal stratification. Observations during 1976 and 1977 (Bishop 1977, Schroeder 1976, Walty 1978) show that the thermocline reached a maximum depth of 11 m one year. Dissolved oxygen generally remained ≤2 ppm below 10 m throughout the year. The lake is protected by surrounding hills, and its sheltered location and basin morphometry apparently limit aeration and circulation.

Spring Lake was cored through the ice in March 1980 with a modified Livingstone piston sampler (Wright 1967). Two cores were taken from the south central portion of the basin in 12 m of water. Spring Lake A (SLA) was 5 cm, and Spring Lake B (SLB) was 8 cm in diameter.

The Spring Lake basal clay sediment will be described below with the description of the basal pollen analysis. The gyttja portion of the core will be described in Part B.

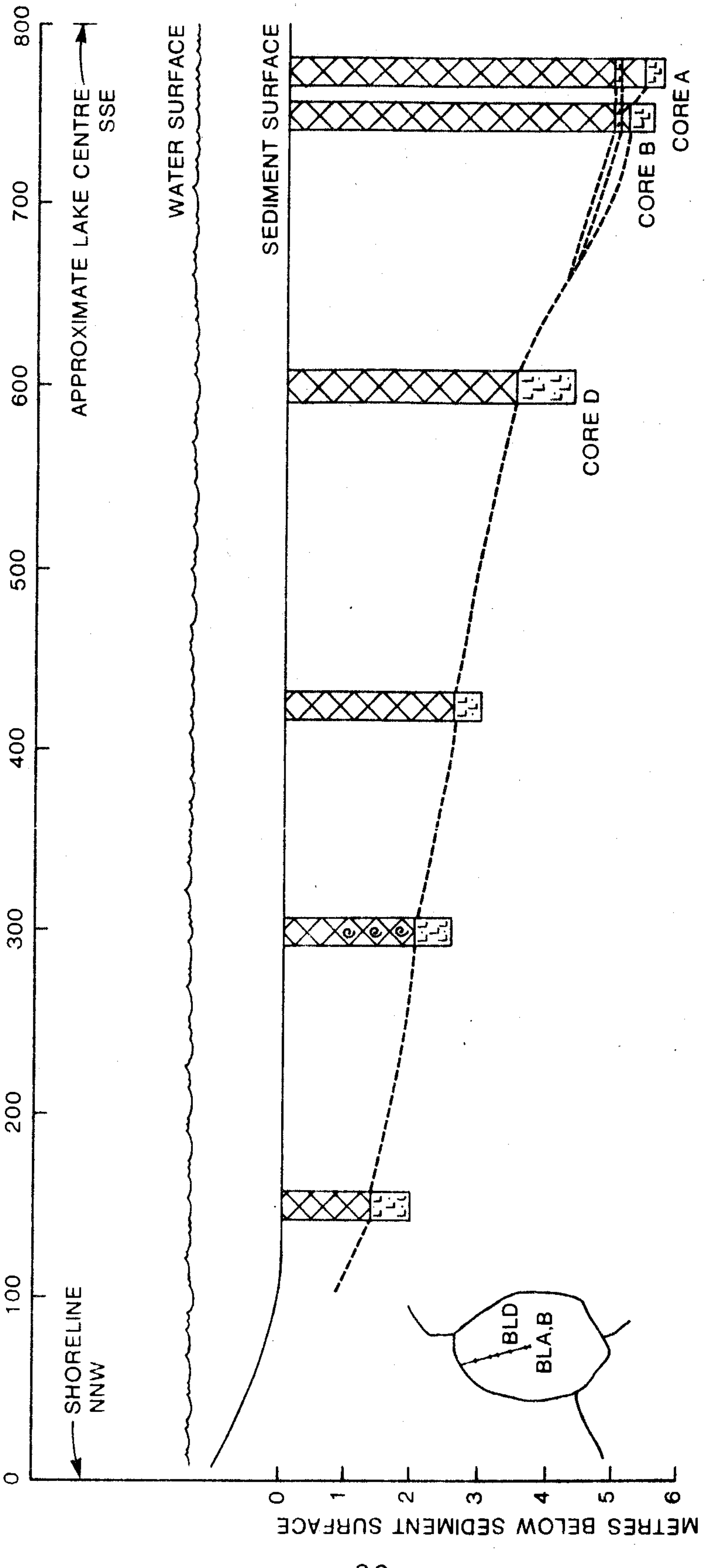
Boone Lake

Boone Lake occupies a broad, shallow basin, and is 1800 m by 1200 m, with an area of about 160 ha. Several cores and soundings of Boone Lake show the basin morphometry. The present sediment surface has been 1.1 to 1.4 m below the ice surface throughout the whole basin during two observation periods in March of 1978 and 1982. Coring suggests that the basal clay-gyttja transition forms a shallow saucer shape with a slightly deeper pocket in the centre of the present basin (Figure 4).

Two 5 cm diameter cores were obtained in March 1978 from the ice platform using a modified Livingstone sampler (Wright 1967). Boone Lake A and B cores (BLA, BLB respectively) were taken within about 5 m of each other. Boone Lake D core (BLD), an 8 cm diameter core, was obtained in March, 1982 from a location about 150 m northwest of BLA and BLB. Both BLA and BLB are characterized by similar stratigraphy (Figure 5). Approximately the upper 5 m of each core was undifferentiated gyttja. Below the gyttja in both cores was a 3 cm thick layer of blue-grey clay. Immediately below this was another layer of gyttja 18 to 44 cm thick which was underlain by a grey clay penetrable by hand coring only to a depth of .5 m. A textural transition took place in the clay sediment at BLB 5.27 m and at BLA 5.50 m from light grey, wet sticky clay above to dark, dry, less sticky clay below.

The depth control of BLB was considered more reliable than BLA as a problem with freezing equipment was mastered when the second core was taken. The clay band noted above, at 4.90 m in BLB, was chosen as a statigraphic marker and the depths shown on BLA have been aligned with BLB. A notable difference in thickness of the gyttja between the upper clay band and the lower clay exists, so that BLA and BLB have been correlated by lithologic sequence using the clay-gyttja transition and clay texture changes as markers (Figure 5). The radiocarbon dates from BLB have been transfered to BLA following the stratigraphic correlation.

Figure 4. Boone Lake basin morphometry.


APPROXIMATE LAKE CENTRE SSE
WATER SURFACE
SEDIMENT SURFACE
CORE A
CORE B
CORE D
SHORELINE NNW
BLD
BLA,B
0
100
200
300
400
500
600
700
800
METRES BELOW SEDIMENT SURFACE
0
1
2
3
4
5
6

III. The Analysis of the Boone Lake Basal Clay

Lithological and chemical analyses

Figure 5 characterizes the sediment of the two cores following Troels-Smith (1955) as modified by Aaby (1979). Fifteen cm more basal clay was recovered in BLB than in BLA. Chemical and pollen analyses were carried out on BLA as most of BLB was used for ^{14}C dating. A carbon and nitrogen analysis, expressed as a percentage of dry weight (Figure 5), was done by the combustion, oxidation, separation and thermal resistivity method using a Perkin-Elmer Model 240 Elemental Analyzer.

The problem of the age of the Boone Lake basal clay

Radiocarbon dates from BLB were reported previously (White *et al.* 1979). These dates are shown beside BLB on Figure 5. Three major problems in interpretation were raised by these dates.

1. The series of dates, apparently indicating an unglaciated sedimentary basin for the last 30,000 years, was difficult to reconcile with local drumlinoid topography.
2. The thin band of clay above the 10,740 ±395 year B.P. date suggested some glacial meltwater or a very high stand of

Glacial Lake Peace over the basin at a late date.

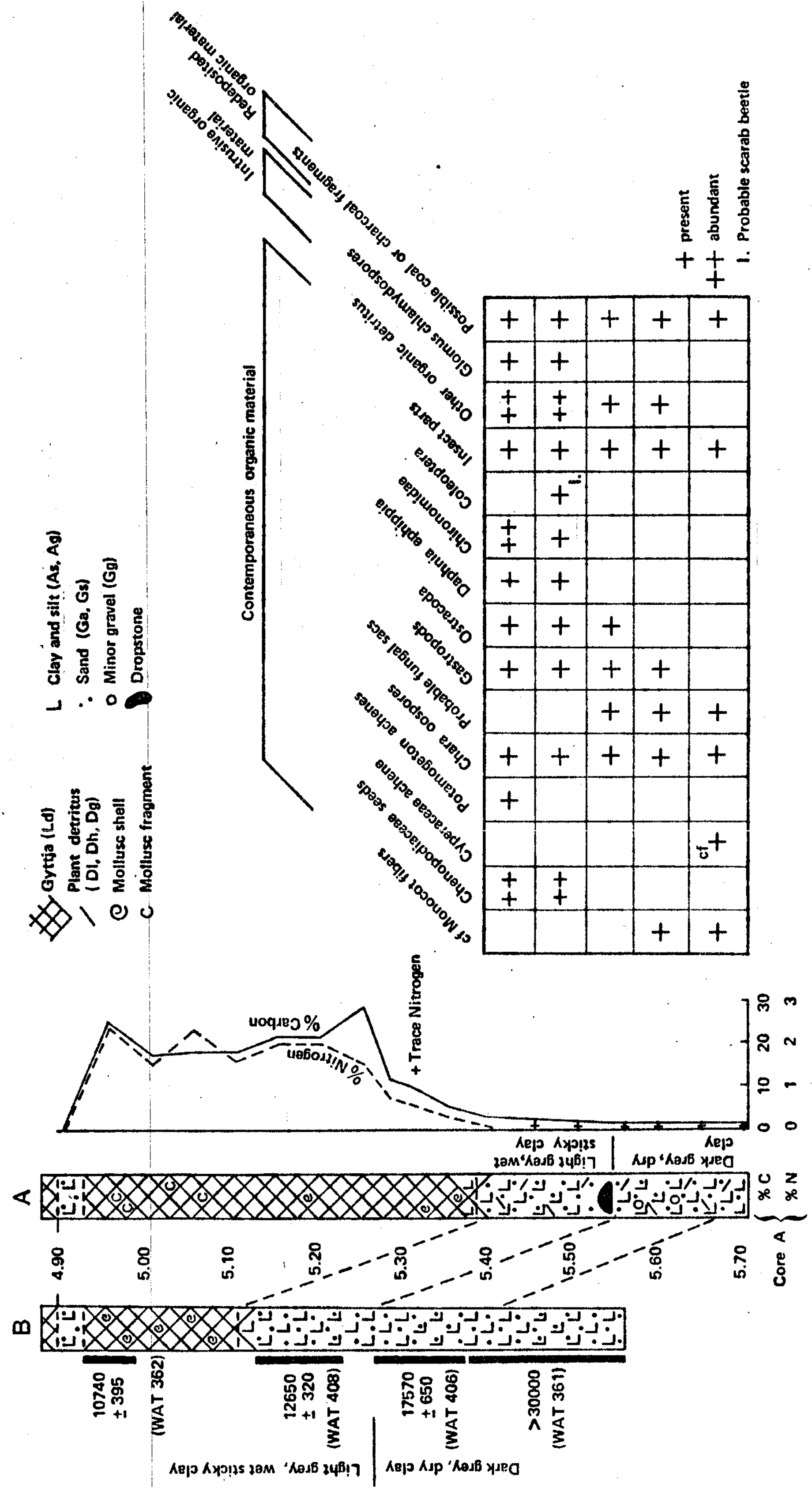
3. The real ages of the sediment samples were uncertain because of the small amount of carbon dated, the unknown degree of contamination of the sediment by reworked Cretaceous-age organic detritus, and the possible incorporation of radiogenically dead carbonate by aquatic organisms.

The authors cautioned that the dates should be considered as maximum ages, but concluded that the >30,000 year B.P. date was likely pre-Holocene and that the 17,570±650 year B.P. date was perhaps much closer to the Pleistocene - Holocene boundary.

Cautions have been issued concerning the radiocarbon dating of sediments which contain little carbon (Olsson 1979) or sediments containing old carbonate or reworked organic detritus (Clayton and Moran 1982, Mathewes and Westgate 1980, Nambudiri _et_ _al_. 1980, and Olsson 1974).

Microfossil and macrofossil analysis of BLA was undertaken to examine the reliability of the reported radiocarbon dates, and to provide a paleoecological interpretation of the sediment. The results of the microfossil and macrofossil analysis of BLA indicated that another core would be desirable, so BLD was obtained. BLD will be described after the results of the analysis of BLA.

Figure 5. Boone Lake A and B basal clay sediment lithology, ^{14}C dates, and macrofossil analyses.

 B
A
4.90
5.00
5.10
5.20
5.30
5.40
5.50
5.60
5.70
Core A
10740
± 395
(WAT 362)
12650
± 320
(WAT 408)
17570
± 650
(WAT 406)
>30000
(WAT 361)
Light grey, wet sticky clay
Dark grey, dry clay
Light grey, wet sticky clay
Dark grey, dry clay
% C
% N
% Carbon
% Nitrogen
+ Trace Nitrogen
0 10 20 30
0 1 2 3
(by weight)
Gyttja (Ld)
Plant detritus (Dl, Dh, Dg)
Mollusc shell
C Mollusc fragment
L Clay and silt (As, Ag)
Sand (Ga, Gs)
o Minor gravel (Gg)
Dropstone
Contemporaneous organic material
Intrusive organic material
Redeposited organic material
cf Monocot fibers
Chenopodiaceae seeds
Cyperaceae achene
Potamogeton achenes
Chara oospores
Probable fungal sacs
Gastropods
Ostracoda
Daphnia ephippia
Chironomidae
Coleoptera
Insect parts
Other organic detritus
Glomus chlamydospores
Possible coal or charcoal fragments
cf
+ present
++ abundant
1. Probable scarab beetle

BLA microfossil analysis

This microfossil analysis was undertaken to estimate the relative proportions of radiogenically 'dead' organic carbon reworked from older geological strata, and carbon derived from organic matter which was living just prior to it final sedimentation. Material in the two categories is designated below as 'reworked' and 'contemporaneous', respectively. The low concentration of organic matter in the clay sediment required the preparation of pollen samples by heavy liquid separation using zinc bromide solution (Schweger 1976), followed by 1.5 to 2 minutes of acetylation, dehydration and mounting in silicone oil.

Nambudiri *et al.* (1980) provided a correction curve for radiocarbon dates from Glacial Lake Agassiz where there is significant contamination by reworked microfossils. Their estimation of the quantity of total reworked organic remains depends on the the proportion of unquestionably pre-Quaternary pollen and spores such as *Aquilapollenites* or *Gleicheniidites*. However, the identifiable microfossils were only a small fraction of the sum of unidentifiable microfossils and other microfossil-sized organic detritus in the Boone Lake sediment. The identification of only clearly definable reworked types could thus lead to a substantial underestimation of the extent of reworked carbon. Extreme flattening and/or degradation of the many unidentifiable microfossils in the basal sediments of Boone Lake suggested that they should also be enumerated as reworked.

A consistent set of standards to categorize primary and redeposited microfossils was therefore needed to improve the estimates of reworking. This sum could then be used to estimate the total proportion of reworked to contemporaneous organic carbon in the sediment.

The staining technique described by Stanley (1966) was assessed for its usefulness in separating reworked from contemporaneous microfossils. Staining for 5 minutes in Safranin 'O' was attempted, but no clear and consistent staining differences were observed amongst the exotic Eucalyptus globulus, the contemporaneous pollen, and the distinct Cretaceous types.

The Thermal Alteration Index (T.A.I.) scale, which is used in petroleum geology research (G. Rouse, personal communication 1981) to separate primary and redeposited microfossils was assessed for its ability to identify reworked microfossils. Various colours ranging from clear to deep amber (1 to 2+) on the T.A.I. chart (Pearson 1981) were evident in the microfossils of the Boone Lake clays, suggesting that this technique might be valuable.

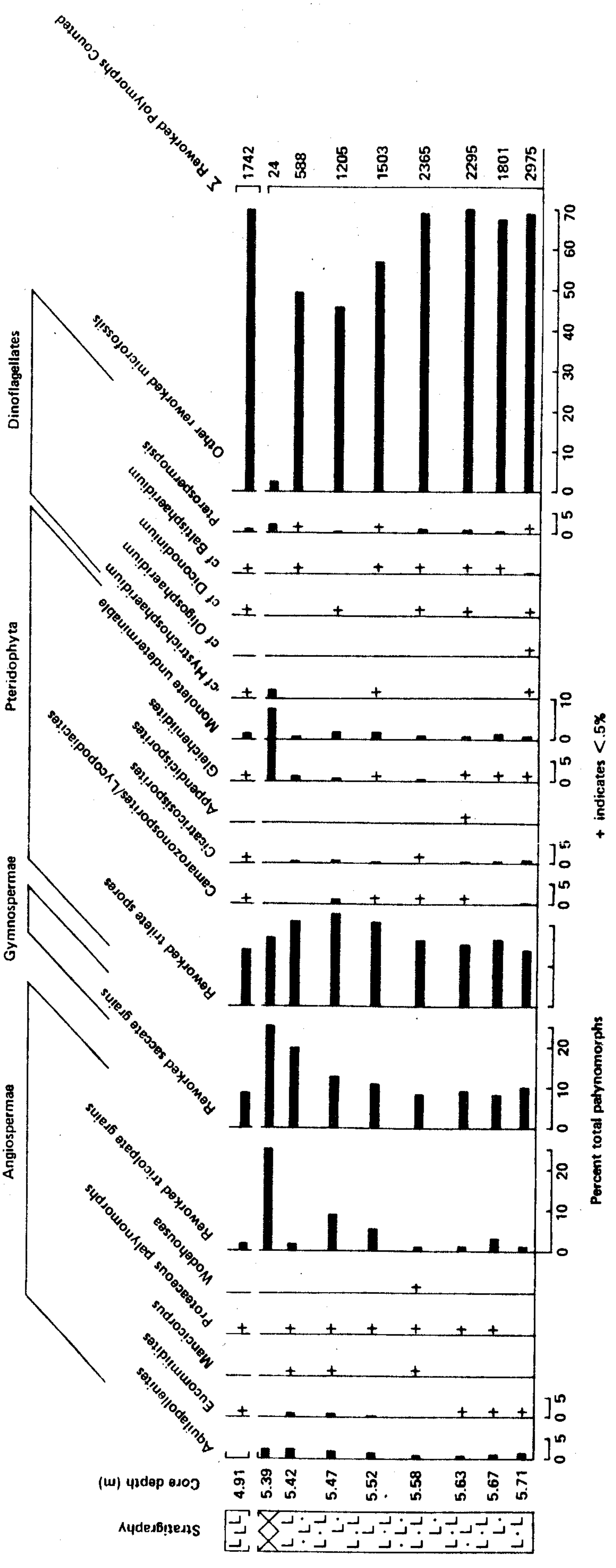
A colour reference for common postglacial pollen and spores was established. Two aliquots of early postglacial gyttja from Boone Lake A (5.39 and 5.45 m) were processed by standard techniques with 1.5 to 2 minutes of hot acetolysis treatment (Faegri and Iversen 1975) followed by a 5 minute treatment in a 5% solution of cold household bleach before dehydration and mounting in silicone oil. Lighting on the Nikon S-Kt microscope was set at 3 volts, and the slides were scanned and counted, scoring all grains on the T.A.I. scale. Considerable variation in the colour values of modern grains was encountered, with thick grains such as Pinus (pine) and Picea (spruce) mostly in the 1+ to 2+ categories, and small dense grains such as Shepherdia canadensis (soapberry) also in the 2+ category. Those with thinner exines and smaller grains such as Populus (poplar), Cyperaceae (sedge), and Poaceae (grass) were mostly in the 1 to 1+ categories. Considerable variation in the colour of clearly modern grains was observed. Eucalyptus was predominantly in the 1 category in one level, and in the 2 category in the other, suggesting that processing factors were significant in determining the colour of the grains. After the colour reference for contemporaneous pollen was established, the clay sediment of Boone Lake was processed by heavy liquid separation, and given the same acetolysis and bleach treatment as the reference samples. It was observed in the basal clay samples that some clearly reworked types such as Aquilapollenties were not as dark as some Eucalyptus. Consequently, the T.A.I. scale was abandoned as a technique for separating reworked and contemporaneous microfossils.

Contemporaneous microfossils were ultimately separated from reworked by a combination of criteria; the identification of the microfossil when possible, an assessement of its degree of degradation or corrosion, and of the degree to which it was crushed. Cretaceous types were easily separated by their distinct morphology. However, generally over 70% of those grains finally classified as reworked could not be clearly identified, but were extremely crushed and/or degraded. Saccate grains and many others commonly show a characteristic shape in equatorial view, but are extremely flattened from the other view, suggesting burial under great pressure. 'Degradation' is common. This is defined as rearrangement of the pollen wall material without noticeable loss, such that the structure or sculpturing can not be resolved. This differs from corrosion, which is pitting or etching of the exine that does not necessarily make the grain unidentifiable. Degraded grains were classified as reworked, but lightly corroded grains might have been considered as contemporaneous, if not severely crushed.

As the purpose of the separation of reworked from contemporaneous microfossils was to assess the reliability of the radiocarbon dates, microfossils were classified as reworked unless there was good evidence that they were contemporaneous. Essentially, a null hypothesis approach was adopted for the categorization of each grain. The classifications shown in Figure 6 represent judgements for which there is no final arbitration of correctness, but the intent was to err towards a conservative estimation of the amount of contemporaneous organic matter in the sediment.

A category of microfossils called 'Undeterminable, Reworked or Contemporaneous' was also established to include microfossils

Figure 6. Boone Lake A reworked microfossil percentage diagram.


Σ Reworked Polymorphs Counted
1742
24
588
1205
1503
2365
2295
1801
2975
Dinoflagellates
Pteridophyta
Gymnospermae
Angiospermae
Other reworked microfossils
Pterospermopsis
cf Baltisphaeridium
cf Diconodinium
cf Oligosphaeridium
cf Hystrichosphaeridium
Monolete undeterminable
Gleicheniidites
Appendicisporites
Cicatricosisporites
Camarozonosporites/Lycopodiacites
Reworked trilete spores
Reworked saccate grains
Reworked tricolpate grains
Wodehousea
Proteaceous palynomorphs
Mancicorpus
Eucommiidites
Aquilapollenites
Core depth (m)
4.91
5.39
5.42
5.47
5.52
5.58
5.63
5.67
5.71
Stratigraphy
0 10 20 30 40 50 60 70
0 5
0 10
0 5
0 5
0 5
0 10 20
0 10 20
0 5
0 5
+ indicates <.5%
Percent total palynomorphs

whose placement was less certain (Figure 7). This included some grains suspected of being contemporaneous, but which were crushed or corroded.

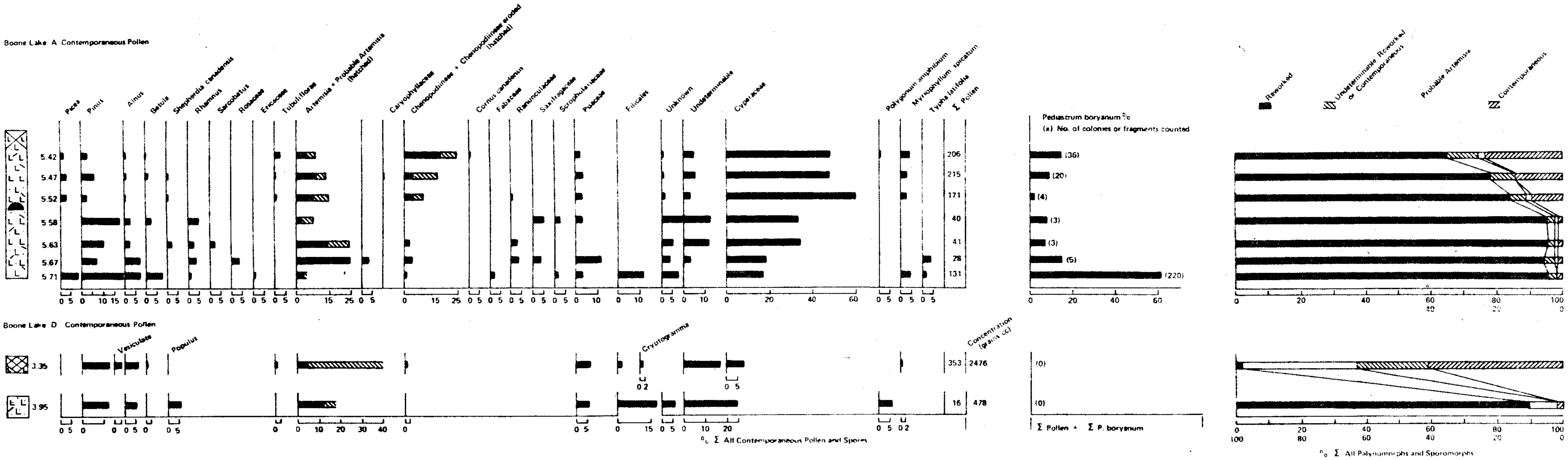
The classified microfossils did not include all of the organic debris on the slides. There were torn fragments of plant tissue and dark fragments which may have been charcoal, which were not tallied in any class, but which were at least as abundant as all of the categorized microfossils. Thus, the technique applied still only classifies a portion of the organic matter in the residue prepared for pollen analysis.

Distinct types of reworked microfossils are classified to family or genus level, and the certainty level of identification is designated according to Birks and Birks (1980:24). Taxonomic references are cited below.

Angiosperm types included Aquilapollenites (Srivastava 1968b,1969b,1969c,1970), Eucommidites (Singh 1971), Mancicorpus (Srivastava 1968a,1968b,1970), Proteaceous palynomorphs (Srivastava 1969a), and Wodehousea (Srivastava 1969d,1970). Reworked tricolpate grains included grains of generally less than 30 micrometers maximum dimension, some of which were presented in polar view showing broad furrows but were extremely flattened meridionally. Other smaller grains of approximately 20 micrometer maximum meridional length had thick exines but a 'fused' appearance without any evidence of verrucae. These latter grains might be badly eroded or badly formed Artemisia (sage) grains.

Figure 7. Boone Lake A and D contemporaneous microfossil percentage diagrams.

Gymnosperm palynomorphs were saccate grains which were



Gymnosperm palynomorphs were saccate grains which were crushed to extremely flattened, and commonly extremely degraded. Many of the grains were so flattened that they appeared to have been subjected to great pressure. No further differentiation was undertaken.

Pteridophytes included *Camarozonosporites/Lycopodiacites* (Singh 1971), which were not separated; *Cicatricosporites* (Singh 1971); *Appendicisporites* (Singh 1971);and, *Gleicheniidites* (Singh 1971). Separate categories were created for monolete and trilete grains that were moderately to thoroughly crushed and/or degraded.

Dinoflagellates included cf. *Hystrichosphaeridium* (Singh 1971), cf. *Oligosphaeridium* (Singh 1971), cf. *Diconodinium* (Singh 1971), cf. *Baltisphaeridium* (Singh 1971), and *Pterospermopsis* (Singh 1971).

The category 'Other Reworked Microfossils' contains those microfossils whose taxonomic status is unclear, but which appear to have been reworked from previous deposits. Much of the organic matter in the residues was placed in this category, and thus its total percentage is by far the most significant in determining the ratio of reworked carbon to contemporaneous carbon. The microfossils tallied in this category were commonly extremely flattened and often torn, and degraded or eroded so that there was little evidence of structure or sculpturing. However, they had smooth exterior shapes over at least part of their surface, and were not randomly torn fragments of plant detritus.

Interpretation of the reworked microfossil diagram

Figure 6 shows the percentage composition of the reworked microfossil spectra in the BLA basal clays. Only a low percentage of microfossils could be classified to family or genus.

There is no notable change in the percentages of taxa throughout the clay sediments except for tricolpate, saccate, and trilete palynomorphs, all of which increase between 5.52 and 5.42 m. There are two possible explanations for this distribution. One could postulate a variation in the source of supply of reworked organic detritus, such that these three taxa steadily increased through time while the others remained constant. Alternatively, one could postulate an overly conservative approach in the assignment of microfossils to the reworked categories, such that increases in contemporaneous pollen and spores are reflected in the reworked percentages. Considering the improbability of the first hypothesis, and difficulty in classification, it is concluded that the latter hypothesis is correct. Furthermore, the Cyperaceae values in Figure 7 (discussed below) indicate an increasing component of contemporaneous pollen above 5.52 m. This supports the hypothesis that these three taxa include contemporaneous palynomorphs improperly assigned to the reworked category.

BLA macrofossil analysis

Macrofossil analysis was carried out on the residual BLA sediment. Organic remains were recovered by rinsing the clay sediment through a 180 micrometer mesh screen, and by decanting to separate the organic material from the coarse mineral fraction. Identifiable plant and animal macrofossils were then picked from the organic residue.

Figure 5 presents only presence/absence data because the number of macrofossils recovered was deemed insufficient for a valid quantitative analysis. The macrofossils were divided into four categories, contemporaneous, intrusive, redeposited, and other organic detritus.

The contemporaneous category includes material which is considered to have been living both shortly before the time of sedimentation and nearby the basin. The fragile but well preserved nature of these macrofossils indicated that they were not reworked from previous sediments or transported from afar. The identifiable contemporaneous macrofossil assemblage from the BLA clay included monocot fragments, Chenopodiaceae seeds, a possible Cyperaceae achene, *Potamogeton* achenes, *Chara* oospores, small fragile sacs about 1 mm in diameter possibly from perfect or imperfect fungi (M. Leggett personal communication 1982), gastropods, ostracods, *Daphnia* ephippia, Chironomid head capsules, and other chitinous insect fragments. A beetle elytron from between 5.46 and 5.52 m is probably that of a scarab (R.

Miller personal communication 1982). The most diverse and abundant assemblages are in the upper clay levels, but even the lowest level contains clearly contemporaneous organics - monocot fragments, _Chara_ oospores, insect fragments, a possible Cyperaceae achene and probable fungal sacs.

Other organic materials include plant fibers and fragments of uncertain provenance. However, the clear evidence of contemporaneous macrofossils through the core suggests that a substantial amount of this material is contemporaneous. It might also contain intrusive and reworked detritus.

Intrusive organic material is represented by _Glomus_ chlamydospores and hyphae which are associated with root mycorrhiza (Berch and Warner 1982). However, no rootlets were noted in this core, and it is possible that these remains were redeposited from an eroded surface, although their fragility makes it unlikely that they were transported far.

Small, dark fragments, possibly of charcoal or a soft coal were found in the coarse mineral fraction of the sediment. Coal is found in the surrounding soils (Odynsky _et_ _al_. 1961).

The microfossil analysis of BLA indicated a very high fraction of contamination by radiogenically dead carbon. On the other hand, the macrofossil analysis gave evidence of contemporaneous organic material throughout the clay sediment. In an attempt to get more reliable radiocarbon ages and more paleoecological information, another core (BLD) was taken from Boone Lake.

Boone Lake D Core (BLD) macrofossil and microfossil analyses

BLD core was taken from Boone Lake using a Nilcon core driver which permitted deeper penetration of the clay.

One metre of clay sediment was obtained near the centre of the modern basin, but a basal stratigraphy differing from BLA or BLB indicated that BLD was not obtained from precisely the same location. Interpretation of the clay-gyttja transition depths in a southeast trending transect across the northwest quadrant of the lake suggests that BLD was taken within 150 m, approximately northwest of BLA and BLB (Figure 4).

BLD penetrates the clay more deeply than BLA. The BLD 3.80 m transition from wet sticky clay above, to drier, denser and darker clay below also takes place at BLB 5.27 m, which is at the top of the 17,570 ±650 year B.P. date. This has been correlated with BLA 5.55 m by a similar textural change. This suggests that the base of BLA (5.71 m) is penecontemporaneous with BLD 3.95 m.

The core was subsampled for %C, %N and pollen analysis and then a longitudinal half of the core was dissected by spatula and screened through a 180 micrometer mesh for macrofossils.

The lowest 27 cm of the core showed a faint dark grey to light grey discontinuous banding (Figure 8). Microscopic examination at x400 of the dark and light material showed that they were both mineral sediments. Clay with little silt made up the thin dark bands, and clay with a higher silt content made up the thicker light bands. Eighty-three couplets were estimated in the 27 cm of rythmites. Interrupting the laminations at several levels were thin beds of sand and pebbles < 5 mm in diameter. At the 4.12 m level is a rounded glacial dropstone 7 cm long by 3 cm in diameter. Clay with sand and till and the occasional pebble <1 cm diameter made up the rest of the clastic segment of the core. The clay below the 3.80 m level was dark, dry and firm, while that above was lighter grey, moister and stickier.

Rootlets were found throughout the clay, the larger ones about 2 mm in diameter running vertically through the core.

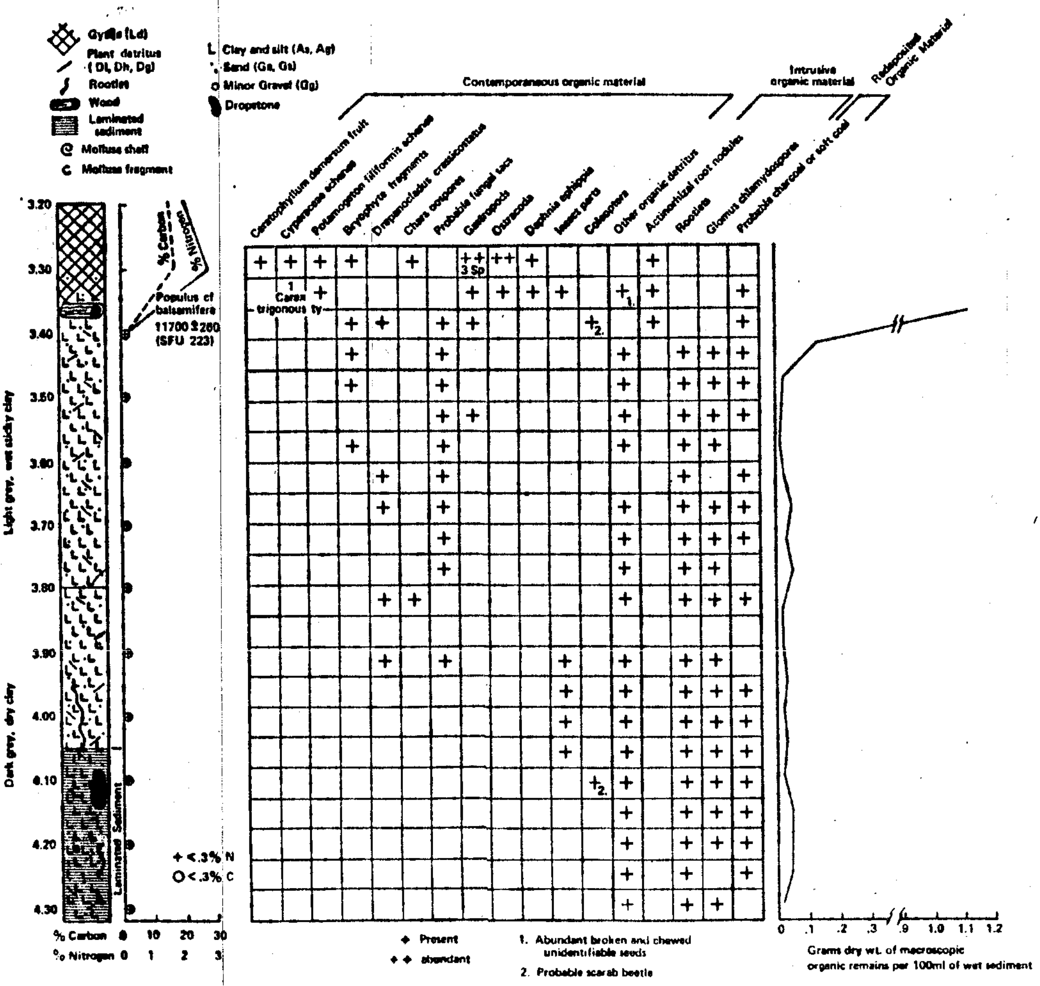
A branch or stem 3 cm thick with the bark adhering was found at 3.37 m. This was identified as Populus cf. balsamifera (balsam poplar) by Mr. Stan Rowe of Forintek. A ^{14}C date of 11,700 ±260 years B.P. (SFU 223) was obtained from this wood.

A rapid clay-gyttja transition occurred above the wood fragment.

Figure 8 presents the percent C and N analysis of the sediments done by the combustion, oxidation, separation and thermal resistivity method using a Carla Erba Elemental Analyzer Model 1106. The analysis was done on dried and pulverized clay sediment. Only trace values were detected throughout the clay sediment, but in the gyttja carbon values rose to >19% and nitrogen values rose to >1.4% by weight.

Figure 8 shows the dry weight per 100 ml of wet sample of organic debris retained in a 180 micrometer screen after the identifiable macrofossil remains and some larger root fragments

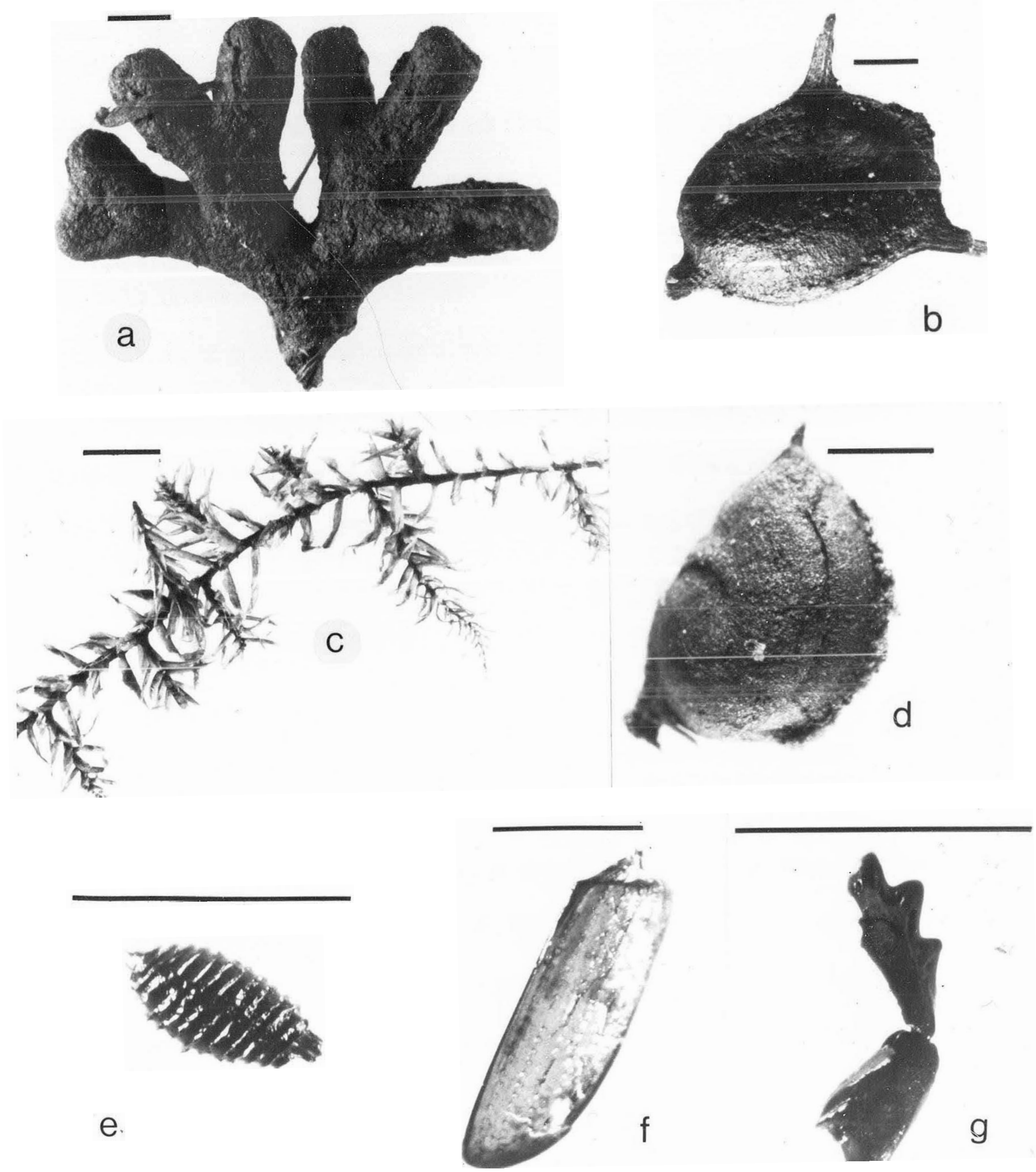
Figure 8. Boone Lake D basal clay sediment lithology, ^{14}C date, carbon, nitrogen, and macrofossil analyses.


Gyttja (Ld)
Plant detritus (Dl, Dh, Dg)
Rootlet
Wood
Laminated sediment
Mollusc shell
Mollusc fragment
Clay and silt (As, Ag)
Sand (Ga, Gs)
Minor Gravel (Gg)
Dropstone
Contemporaneous organic material
Intrusive organic material
Redeposited Organic Material
Ceratophyllum demersum fruit
Cyperaceae achenes
Potamogeton filiformis achenes
Bryophyte fragments
Drepanocladus crassicostatus
Chara oospores
Probable fungal sacs
Gastropods
Ostracoda
Daphnia ephippia
Insect parts
Coleoptera
Other organic detritus
Actinorhizal root nodules
Rootlets
Glomus chlamydospores
Probable charcoal or soft coal
3 Sp
1 Carex trigonous ty
3.20
3.30
3.40
3.50
3.60
3.70
3.80
3.90
4.00
4.10
4.20
4.30
Light grey, wet sticky clay
Dark grey, dry clay
Laminated Sediment
% Carbon
% Nitrogen
Populus cf balsamifera 11700 ± 260 (SFU 223)
+ < .3% N
O < .3% C
% Carbon 0 10 20 30
% Nitrogen 0 1 2 3
+ Present
+ + abundant
1. Abundant broken and chewed unidentifiable seeds
2. Probable scarab beetle
0 .1 .2 .3 .9 1.0 1.1 1.2
Grams dry wt. of macroscopic organic remains per 100ml of wet sediment

had been picked out. It represents the weight of material included in the category of ' Other organic debris'. It probably contains contemporaneous organic debris and some intrusive root fibers. It does not include possible charcoal or soft coal fragments. Analysis of pulverized organic detritus from 3.80 m to 4.12 m yielded C values of 31.4% to 37.6%, and N values of 1.3% to 1.9%. Other fragments thought to be rootlets were 8.1% to 23.9% C and .4% to 1.9 % N. The values on organic debris were less homogeneous than those of powdered clay samples. The organic detritus content of the clay is homogeneous, increasing markedly only at the 3.35 to 3.40 m level. The poplar fragment was not included in the %C and %N analysis at this level.

Figure 8 also presents the analysis of the identifiable macrofossils in BLD (illustrated in Figure 9a,b,d-g). The contemporaneous organic assemblage is more diverse than in BLA, probably because of a larger sample size. The earliest evidence of contemporaneous organic material in the core comes from the 4.07 to 4.12 m segment. Beetle fragments were recovered and tentatively identified as a scarab (R. Miller personal communication 1982), which must have been intact before the sediment was wet screened (Figure 9f,g). Above that level, insect parts occured, and fungal sacs, Drepanocladus crassicostatus fronds (Dr. Jan A. Janssens personal communication 1982) and unidentifiable bryophyte fragments are consistently represented. Above the 3.40 m level the contemporaneous macrofossil assemblage is most diverse. The

Figure 9. Photographs of macrofossils from Boone Lake A and D and from Spring Lake A: a, actinorhizal root nodule (BLD 3.35-3.40 m); b, *Ceratophyllum demersum* achene (BLD 3.25-3.30 m); c, *Drepanocladus exannulatus* frond (SLA 4.67 m); d, *Potamogeton filiformis* achene (BLD 3.25-3.30 m); e, *Chara* oospore (BLD 3.80-3.87 m); f, elytron, probably of a scarab beetle (BLD 3.80-3.87 m); g, beetle leg (BLD 4.07-4.12 m). Scales above each photograph represent 1 mm.


a
b
c
d
e
f
g

beetle in the 3.35 to 3.40 m segment is also probably a scarab (R. Miller personal communication 1982). Actinorhizal root nodules were found in the same level (Figure 9a). Potamogeton filiformis achenes (Figure 9d) in the sediment were identified by B. Warner (personal communication 1982) and a Ceratophyllum demersum achene (Figure 9b) was also found at this level.

The category of other organic debris has been previously defined and may contain a mixture of carbon from three sources, as in BLA.

Actinorhizal root nodules (Baker and Miller 1980) are likely intrusive organics. They are produced by N fixing endophytic bacteria. No ultrastructural analysis was performed on the root nodules,but the pollen analysis of the clay-gyttja transition in BLA demonstrates the presence of Alnus (alder) and soapberry, and these actinorhizal root nodules may belong to either taxon.

Dark fragments of soft coal represent reworked radiogenically dead material.

Microfossil analyses were done at 3.95 m where there was clear macrofossil evidence of contemporaneous organics, and at the 3.35 m clay - gyttja transition. In both cases 5 ml of sediment was processed by the heavy liquid method. The analyses are plotted on Figure 7. A Eucalyptus spike of 194,160±5058 grains was added by Stockmarr tablets to 5 ml of sediment to ensure accurate concentration estimates.

The 3.95 m level pollen sum was low such that the nominal percentages are not meaningful. Contemporaneous pollen including pine, alder, poplar, sage, grass, and Filicales spores are present. Sedge is not represented in BLD, but the undeterminable pollen is likely sedge. Reworked palynomorphs constituted 90% of all identified palynomorphs, and contemporaneous grains total only 1%, similar to the lower levels of BLA. A total of 1299 _Eucalyptus_ grains were tallied for 16 contemporaneous grains. The estimated contemporaneous pollen concentration for BLD 3.95 m is 478 grains cm^{-3}.

The 3.35 m pollen analysis produced a pollen sum of 353 so that the percentages have interpretative value. The sum is high but the spectrum is impoverished. The sage percentage may range from 5% to 40% because of identification problems described below. However, the low spruce and pine percentages and well-represented sage suggests a correlation of this level with the spectra in the Boone Lake A,B composite diagram (Part B) between 5.24 and 5.40 m., or BL zone 2. The undeterminables in the BLD spectrum may be more eroded cf _Populus_ and Cyperaceae grains having high percentages in the BLA,B diagram at these levels. At 3.35 m the reworked palynomorphs are reduced to 2% of all palynomorphs identified. A total of 5536 exotic grains were tallied for the 353 contemporaneous grains identified. The estimated concentration of contemporaneous pollen is 2476 grains per cm^{-3}. No _Pediastrum_ colonies were identified in either BLD level.

Validity of the radiocarbon dates

A prime objective of the microfossil and macrofossil analysis was the determination of the reliability of the radiocarbon dates from BLB. Some important insights have emerged from this work.

The microfossil analysis of BLA 5.58 to 5.71 m shows that reworked microfossils are 95% or more of all of the palynomorphs, although it has been argued above that the percentage of reworked palynomorphs was overestimated. These levels correspond to the approximate middle of the core segment that yielded the 17,570±650 years B.P. date and the upper part of the core segment that yielded the >30,000 years B.P. date. If the microfossil component alone were considered, the contamination of the dates by dead carbon would be minimally sufficient to produce dates 2 half lives too old (Stuckenrath 1977).

The reworked microfossil content drops to 65% at 5.42 m, which is near the top of the core segment that yielded a date of 12,650± 320 years B.P. Contemporaneous microfossils rise from 1.6% to 23% between 5.58 and 5.42 m. Thus, even at 5.42 m the percentage of radiogenically dead carbon indicated by the microfossil analysis should be sufficient to produce a date at least one half life too old. However, the date is clearly not that much too old. Considering its position just below a clay - gyttja boundary, and the date of 10,740± 395 just above it, the

12,650 ± 320 years B.P. date appears approximately correct. Confirmation is found in the fragment of poplar encountered at the clay-gyttja transition in BLD, and dated at 11,700± 260 years B.P. (SFU 223). Although the chance that this date and the equivalent date in BLB, 12,650 ±320 years B.P., are contemporaneous is between 1% and 5% (Polach 1972), the BLB dated core segment is stratigraphically somewhat lower than the poplar fragment, and has some reworked organic contamination. The correlation suggested above between the BLD 3.35 m pollen spectrum and BLA,B zone 2 supports the interpretation that the 12,650±320 year B.P. date is approximately correct.

No other radiocarbon dating was done on BLD in an attempt to verify the BLB dates. There are three identified sources of carbon in the sediment; 1) reworked organic material, 2) contemporaneous organic material, and 3) younger intrusive roots. The difficulty of separating these various fractions and the impossibility of dating them separately, given the small sample sizes and low carbon content, renders futile further radiometric dating.

No attempt was made to adjust the BLB dates for an old carbon error as Nambudiri et al. (1980) have done. The impossibility of accurately assessing the relative contribution to dated carbon of the contemporaneous macrofossils and microfossils, and the lack of knowledge of the real age of the contemporaneous organic material means that no reliable correction can be made of the radiocarbon dates from the Boone

Lake clay sediment.

Chronological evidence leading to a more certain answer is found in the approximate 83 rhythmites visible in the lowest 27 cm of BLD. On the assumption that these couplets are annual deposits, a deposition time of less than a century is indicated for one third of the basal clay. The overlying clay is not laminated, and in the absence of other data, one can only assume an equal sedimentation rate.

The argument above suggests that the clay possibly accumulated in about 250 years, and that the sequence of ^{14}C dates can be explained by an increasing fraction of contemporaneous organic material with a decreasing fraction of reworked organic detritus. An environment of decreasing clastic sedimentation and stable vegetation production, or increasing vegetative production and stable clastic sediment, or both, could produce this date series. This conclusion is accepted as the basis for subsequent interpretation.

Alternatively, it must be acknowledged that a longer period of accumulation could be indicated. The laminations at the base of BLD might not be annual, or the sedimentation rate in the clay above might be substantially slower. The contemporaneous macrofossils have produced an acceptable 12,650 year B.P. date, although the level of contamination by reworked detritus indicated by the microfossils is >50%. Some contemporaneous microfossils and macrofossils also occurred in the core segment that was dated at 17,570± 650 years B.P. Therefore, the real age of that core segment might be substantially older than the 12,650 years B.P. date.

Palaeoecological interpretation of the contemporaneous pollen diagram

The spectra of pollen or spores interpreted as contemporaneous with the final depostion of the sediment are shown in Figure 7.

All taxa are included in the pollen sum. In the bottom 4 levels the sums of contemporaneous grains are low, though thousands of reworked microfossils were tallied in the same levels. Thus little significance can be attached to percentage fluctuations of contemporaneous taxa. BLA contemporaneous pollen is discussed first.

Spruce is intermittently represented in the lower levels, but is continuously represented above 5.52 m. Pine representation is continuous, but is most likely transported from some distant source, as might be spruce. As noted above, the number of conifer grains has probably been reduced by inclusion of some of the more crushed grains with the reworked saccate grains.

Alder might be a local shrub, but is also possibly transported from a distant source (Colinvaux 1981). Birch, probably a shrub, and soapberry are likely local species, and might be more consistently represented throughout the basal section given higher pollen sums. *Rhamnus* (buckthorn) is probably a local wetland shrub, and is consistently represented in the lower four levels, and then disappears even with increasing pollen sums. Buckthorn, soapberry, and alder are nitrogen fixers, and their presence might be expected in a mineral soil landscape.

The Tubuliflorae have a continuous and possibly expanding presence above 5.52 m.

The Artemisia sum is followed by a category called probable Artemisia. The grains included in the latter category were small (generally under 20 micrometers in length) and tricolpate with a thick exine, a 'melted' appearance and evidence of verrucae . It is suggested that these are contemporaneous Artemisia pollen which have either been poorly formed, or undergone some degradation process. They have been classified as probable Artemisia and separated from the unquestionable Artemisia so that interpretation can rest on taxonomically certain results. More thoroughly eroded or degraded grains were placed in the reworked or undeterminable, reworked or contemporaneous categories. Sage is present throughout the clay sediments, and notably at the 5.67 m level all sage are classed as unquestionable.

The Chenopodiineae are also separated into categories for well-preserved grains, and those which are eroded and/or somewhat crushed or torn. This taxon is continuously represented except at 5.58 m, and there appears to be a consistent increase in abundance in the 5.52 to 5.42 m levels.

Grass is consistently represented except at 5.63 m.

The taxon Sarcobatus occurs once, but being a dryland species (Hitchcock and Cronquist 1973:101) it probably represents long distance transport. The other taxa Rosaceae, Ericaceae, Caryophyllaceae, Fabaceae, Ranunculaceae, Saxifragaceae, Scrophulariaceae, and Cornus canadensis occur in such limited numbers that no inferences can be made about their distribution through time, except that they represent herbs or shrubs which must have been present locally at some time. The unknowns are more numerous in the lower four levels, and probably represent herbaceous flora. The meaning of the peaks of 'Undeterminable but Probably Modern Grains' at 5.63m and 5.58 m is unclear, if the values are indeed significant.

Sedge pollen is the most abundant type throughout the core, and is the most useful indicator of local vegetation. Sedge grains are thin-walled, and are probably susceptible to rapid erosion. The grains in this class were often very well preserved and uncrushed, or were crushed but not extremely flattened, and the exine sculpturing was discernable. This preservation indicates that they represent primary deposition. The lower four levels have values consistently below 34%, and the upper four levels are consistently above 45%, suggesting an increase in abundance. These sedges might represent wetland or upland habitats.

Myriophyllum spicatum ty. (Mathewes 1978) is represented by well preserved grains at 5.71 m, and then above 5.52 m. M.

spicatum ssp. exalbescens is inhibited by clay substrates (Neumeyer 1979). The lack of competition with other aquatics must have permitted Myriophyllum to grow on this clay substrate where it can not in Holocene situations.

Typha latifolia is represented by only one grain and a tetrad fragment in the lowest two levels.

IV. Spring Lake Basal Clay Microfossil Analysis

The Spring Lake sediment between 4.64 m, the lowest gyttja level, and the base of the core at 5.02 m is clay. The upper 18 cm contains clay with pebbles and contemporaneous macrofossils, including *Drepanocladus exannulatus* (Figure 9c) and *D. crassicostatus* fronds, and the lower 19 cm is a clay with some macrofossils. Pollen analyses were done at 6 levels between 4.70 m and 5.02 m. The upper 5 levels were prepared from 1 ml samples using the Nitex screening method (Cwynar *et al.* 1979) and Stockmarr *Eucalyptus* tablets. Taxa represented two or more times in the upper 5 levels were *Abies* (fir), spruce, pine, birch, willow, Tubuliflorae, sage, grass, undifferentiated Filicales, sedge, and *Typha latifolia*. Sage was most consistently and abundantly represented. Concentrations were generally below 1200 grains per cc and pollen sums too low to make percentage calculations reliable.

The lowest sample at 5.02 m was prepared from 20 ml of sediment using heavy liquid separation (Schweger 1976) and a *Eucalyptus* solution. The pollen analysis gave anomalous results. Pollen was much more abundant in this level than in those above. However, due to a technical problem with the combination of *Eucalyptus* solution and heavy liquid separation, the pollen concentration must be estimated indirectly, rather than calculated directly. Two pollen preparations were analysed at the 4.92 m level, one prepared by Nitex screening and one prepared by heavy liquid separation. A pollen concentration of 671 grains per cc was estimated from the Nitex screening concentrate. The heavy liquid preparation for the same level also showed sparse pollen when the slide was scanned. Pollen was much more abundant than this in the 5.02 m heavy liquid preparation, indicating a higher concentration than 671 grains per cc. The concentration at 5.02 m is thus roughly estimated at 5000 to 10,000 grains per cc.

A pollen sum of 578 grains was counted at 5.02 m. The spectrum is; spruce 11%, pine 54%, alder 3%, birch 20%, sage 1%, sedge 2%, and Typha latifolia 2%. fir, Corylus (filbert), soapberry, Rosaceae, Ericaceae, Chenopodiineae, grass, Linnaea, Viburnum, Myriophyllum, Athyrium type, unknowns and undeterminables also occured at less than 1% per taxon.

The very high spruce, pine, and birch values are anomalous compared to the pollen spectra in the clays above this level. This 5.02 m spectrum seems most closely related to that found in Spring Lake at 4.20 m, dating to about 10,300 years B.P. The anomaly can not be attributed to an inverted core segment, but the possibility of a stratigraphic inversion must be considered. The basin is steep-sided and postglacial slumpage or kettle melt-out could have disrupted the stratigraphy, except that the gyttja above the clay can be shown to be stratigraphically undisturbed by comparing the pollen spectra to BLA,B (Part B). It therefore seems likely that the lowest clay level is a primary deposit, capped by a layer of pollen-poor clay deposited by glacial meltwater. However, the spectrum is from the bottom of the core and it can not be verified by the analysis of other material.

A sample of Watino Bed silt (Westgate et al. 1972) from near the top of the mid-Wisconsinan sequence was provided by Dr. John Westgate for pollen analysis. Spruce was found to dominate the upland assemblage, whereas the pine percentage was very low. The SLA sediment therefore does not appear to be a mid-Wisconsinan non-glacial deposit. The possibility that it represents some real Late Wisconsinan vegetation pattern must be entertained, but no further conclusions are possible from the present data.

V. Palaeoecology and Geochronology of the Saddle Hills and Peace River District at the Late Wisconsinan - Postglacial Transition

Boone Lake local reconstruction

The Boone Lake sediment contains a record of deglaciation and early vegetation development. A consideration of surrounding glacial geology is important to the interpretation of this period. Evidence at hand suggests the following geological senario for the development of the early Boone Lake sedimentary record.

Ice overrode or was closely adjacent to Boone Lake during the Late Wisconsinan advance. A Laurentide ice mass moving around the Clear Hills (Figure 1) advanced over the northern Saddle Hills. Boone Lake was apparently near the southeastern terminus of this ice mass.

Present Boone lake occupies a basin which once contained a larger meltwater pondage. The southwestern arm of the pondage down Boone Creek was probably blocked by an ice mass during deglaciation. The ice which formed the western edge of an enlarged Boone Lake ponded the water sufficiently high to produce the eastern shoreline by wave or ice-thrust action. Meltwater also flowed into Boone Lake via the channel to the northwest and meltwater drained from the basin through the channel to the southeast, deepening it and lowering the level of

Boone Lake. Ablation of the stagnant ice block to the west permitted development of the Boone Creek drainage and lowered the level of Boone Lake to more or less its present level.

The evidence from the Boone Lake cores fits well with the scenario presented above.

Ice damming produced a pondage deep enough to avert sediment disturbance by wave action, resulting in laminated sediments. These couplets were probably deposited in the lake associated with the high shoreline to the east. The beginning of the BLD record was previously estimated at 250 years older than the 11,700±260 year B.P. date.

Couplet deposition likely ceased because of lowered water levels allowing wave mixing of the sediment. Ice ablation or a deepening of the meltwater channel could be responsible for lowered water levels. Probably the transition to sticky clay at BLD 3.80 m was also caused by changes in water depth, the rate of mineral sedimentation, and organic sedimentation.

Although BLD contains a longer segment of clay than BLA, this clay is 2 m higher in the basin than BLA or BLB. It is supposed that the laminated record is continuous across the basin, dipping towards the centre, and that a deeper penetration of the clay at BLA or BLB would have penetrated the laminae. A lower basin centre, the melt of a buried ice block,or some channel formation resulting from the meltwater inflow may explain the dip of the clay towards the southeast. It appears that toward the end of clay deposition the water level in the whole basin was low enough that BLD was nearshore or only occasionally inundated, while BLA and BLB were underwater and accumulating a richer paleoecological record. Alder or some other nitrogen fixing species formed actinorhizal root nodules near the top of the BLD clay and sent rootlets down into the clay below.

The lowest record of contemporaneous organic deposition is found in BLD near 4.10 m. Beetle remains, probably of a scarab, occur in the sediment at the same time as evidence of ice-rafting. The beetle indicates habitat available for a ground-dwelling insect. Other insect fragments occur consistently in the 20 cm above the beetle, and at 3.90 m a _Drepanocladus_ _crassicostatus_ fragment and probable fungal sacs show some local plant growth.

Pollen analysis at 3.95 m produced a very low sum (16), sufficient only to indicate that pine, alder, poplar, sage and grass pollen, and some fern spores were entering the sediment at a rate of less than 200 grains per year. Possibly the pine, alder, and sage should be attributed to long-distance transport. No _Pediastrum_ colonies were observed.

Although by depth BLA 5.71 m appears contemporaneous with BLD 3.95 m, the microfossil and macrofossil assemblages are different enough that one must conclude that BLA postdates BLD 3.95 m, or was receiving more organic sediment, perhaps by sediment focusing (Davis and Ford 1982).

BLA contains contemporaneous pollen of pine, spruce, alder, birch, buckthorn, sage, chenopods, legumes, grasses, *Typha*, *Myriophyllum* , and sedges. Abundant *Pediastrum* colonies were also noted, indicating algal productivity. Local wetland and aquatic vegetation *Myriophyllum*, *Typha*, sedge, grasses and Scrophulariaceae are indicated by the microfossils because they are unlikely attributable to long distance transport. The macrofossil assemblage of BLA adds monocot fibers, probably from grass or sedge, a possible Cyperaceae achene, *Chara* oospores, probable fungal sacs and insects to the aquatic or wetland assemblage.

Low sums of pollen up to BLA 5.58 m make interpretations of percentages and trends unreliable. Buckthorn occurs consistently and another nitrogen-fixing shrub, soapberry, is added to the assemblage, as are Ericales and Rosaceae. Brassicaceae, Ranunculaceae, and Saxifragaceae are added to the local herb assemblage. Pollen input is low in these levels, and *Pediastrum* productivity begins to decline. Gastropods also occur in the sediment.

At BLA 5.58 m a notable transition takes place. The input of contemporaneous pollen begins to increase relative to the reworked microfossils, although ice-rafting of clasts still is evident. Higher pollen sums were possible in counting and percentage trends thus have some interpretative value.

The most notable microfossil change at 5.58 m is an increase in sedge. Chenopodiineae also consistently increase and grass values are low. Sage appears to have declined somewhat. Tubuliflorae values are low, but consistently present, and soapberry occurs in two levels. The decline of pine, spruce, alder, and birch values is probably a function of the sedge increase. Pine grains are likely transported from a distance, but spruce may be a limited regional element. Myriophyllum continues to grow in the pond and Polygonum amphibium was present at 5.42 m. Pediastrum productivity seems to rise at 5.47 m and 5.42 m.

The macrofossils of BLA above 5.58 m show increasing local plant life. The macrophytic alga Chara continued to grow in the pond, probably indicating basic conditions (Wood 1967). Chenopod seeds show that the Chenopodiineae pollen is of local origin, probably from the muddy lake shore, and Potamogeton achenes appear although the pollen was not found. Gastropods, ostracods, Daphnia and Chironomid larvae lived in the lake, while the probable scarab beetle and other insects fell in or were washed in from the uplands or littoral area.

Similar diversity in the macrofossil assemblage does not occur in BLD until above the poplar fragment. Actinorhizal root nodules above 3.40 m suggest a shore habitat and this may explain the presence of Drepanocladus crassicostatus fronds and the absence of Chara oospores and Daphnia ephippia at the same level although they occur in BLA. A more complete assemblage is found in the postglacial gyttja above the poplar fragment. These macrofossils show the presence of Ceratophyllum demersum, *Potamogeton filiformis*, *Chara*, sedge, three species of gastropods, ostracods, and *Daphnia*. Many broken and apparently chewed seeds, thus rendered unidentifiable, were also found in the lower gyttja.

The pollen analysis of BLD 3.35 m shows little variety, but 13% pine may indicate pine approaching the region. The high values for probable *Artemisia* makes interpretation of that taxon unclear. Grasses and chenopods were present at this level. A substantial increase in pollen concentration to 2500 grains cm^{-3} is notable.

Regional geochronology

The Boone Lake sediment cores provide no firm evidence of an unglaciated area prior to 12,000 years B.P. The evidence of a Laurentide ice mass near Boone Lake just before 11,700±260 years B.P. gives chronological control for Mathews' (1978,1980) interpretation of Laurentide and Cordilleran ice coalescence during the Late Wisconsinan. However, the ice must have been ablating by at least 12,000 years B.P. as the early vegetation record from the sediment predates 11,700±260 years B.P. by 200 to 300 years. Moreover, the base of the sediment core does not terminate in a till, but represents the total penetration that could be achieved during the coring operations. The paleoecological insights provided by this record are limited by the low ratio of contemporaneous pollen to reworked palynomorphs, and the low total concentration of microfossils and macrofossils in the clay. Nonetheless, the record of local vegetation prior to 11,700±260 years B.P. is clear, and the record thus contributes to regional problems of deglaciation and revegetation.

Recent evidence from surficial geology of the Peace River district suggests that the withdrawal of Glacial Lake Peace took place earlier than previously supposed. The radiocarbon date ≥11,600 years B.P. (I 2244a) on the mammoth tusk from the Portage Mountain moraine (Mathews 1978,1980) has been important in interpreting the regional deglaciation chronology. In the absence of other evidence it has been interpreted as approximately dating the deposition of the Portage Mountain moraine and a coeval Bessborough Stage of Glacial Lake Peace (Mathews, 1978, 1980). The tusk has recently been redated at 25,800±320 years B.P. (GSC 2859, Mathews 1980). This date now fits well with a date on bone from the Ostrero Gravel Pit of 27,400±580 years B.P. (GSC 2034, Mathews 1978), a date on wood and peat of 27,400 ±850 years B.P. from the Watino Beds (I 4878, Westgate <u>et</u> <u>al</u>. 1972) and a date on plant remains of 25,940±380 years B.P. (GSC 573) from the Finlay River in the Rocky Mountain Trench (Rutter 1977) which predate the last major ice advance. It appears that this tusk was from a mammoth living during the mid-Wisconsinan non-glacial interval, whose tusk was incorporated into the Portage Mountain moraine. It thus sets a maximum age for that moraine and the associated Bessborough stage of Glacial Lake Peace, leaving those events otherwise undated.

Extensive mound features in sand to clay sediments have been noted by several workers in the Peace River district (Henderson 1959; Mathews 1963,1978,1980; Odynsky _et al_. 1961; and Reimchen and Rutter 1971), who have all interpreted them as periglacial phenomena, but these features have not been firmly dated. As the Bessborough Stage of Glacial Lake Peace has now only a maximum age, it is possible that a withdrawal of the high proglacial pondages before 11,600 years B.P. would expose large areas of glaciolacustrine sediment to a periglacial climate.

An estimate for the minimum age of periglacial activity may be derived from the pollen analysis of the Boone Lake and Spring Lake gyttjas (Part B). Pine percentages rise to above 20% in the core segment dated at 10,740±320 years B.P. in Boone Lake, and well above 20% at 10,800 years B.P. in Spring Lake.One may therefore consider it to be regionally present at least as a minor element (Webb and McAndrews 1976, Lichti-Federovich and Ritchie 1968, and Ritchie 1976). The sediment dates are reliable gyttja dates. The pine is probably _Pinus contorta_ (lodgepole pine) which is presently found in that region (Hosie 1973), but it could also be _Pinus banksiana_ (jack pine) which reaches its western limit in this latitude in the eastern Peace River district (Hosie 1973) but might have migrated to the eastern boreal forest from a western centre (Ritchie 1976). Lodgepole pine's range in British Columbia and the southwestern Yukon

(Hosie 1973, Porsild and Cody 1980) extends only into the southern fringe of discontinuous permafrost (Brown 1973). Jack pine's range extends farther north down the MacKenzie River (Hosie 1973) into the region of widespread discontinuous permafrost (Brown 1973), but it is not regionally common (Porsild and Cody 1980). The present distribution of pine probably represents a climatic limit for the species. Krajina et al. (1982) note that lodgepole pine has a lower frost resistance in continental climates than jack pine, black or white spruce, or tamarack. It is therefore tentatively proposed that the presence of pine in sums greater than 20% sets the minimum regional time limit for periglacial activity. This is at least 10,400 years B.P., if account is taken of the standard error in the radiocarbon dates.

Mathews (1963) has interpreted the mound features as having developed under shallow ponds by permafrost pressure, somewhat like pingos. The pond sediment commonly overlying the mounds as the remains of the original pre-mound pond may extend beyond the mound base. Two dates on Limnaea shells in the pond sediments of 9960±170 years B.P. (GSC 1548) and 10,400±170 years B.P. (GSC 1564, Lowdon and Blake 1973:28) would by this interpretation predate extensive periglacial activity, which can not be reconciled with the climate suggested by the pollen record of that time (Part B). Subsequently, Bik (1968,1969) has examined similar mound features in southern Alberta and has generally concurred with Mathews' interpretation, suggesting also that they formed along the shore of proglacial lakes. The typical central depression of most mounds could be produced by the melt of a buried ice core at the end of periglacial conditions. This basin could presumably have contained a pond subsequent to the cryogenesis of the mound. Consequently, the 9960 and 10,400 year B.P. dates would not be at odds with the minimum age of periglacial activity proposed above. However, this interpretation does not concur with the mounds Mathews has described. The pond sediments' extension beyond the mound base suggests that they indeed belong to a pre-mound pond. Consequently, the shell dates can not be conclusively reconciled with the interpretation proposed here.

If the interpretation based on the pine presence is correct, the development of periglacial mound features along the Little Smoky River north of Valleyview and south of Peavine Creek requires ice and proglacial pondage recession to lower than the late Clayhurst Stage, but perhaps not as low as the Indian Creek Stage (Mathews 1980:Figure 5E,5F), before 10,400 years B.P. Supporting minimum ages for lake withdrawal to that point are provided by a radiocarbon date of 10,200±110 years B.P. (GSC 1998, Lowdon et al. 1977) from Dollar Lake west of Highway 34 and north of Little Fish Creek, and by a date of 11,000 ±200 years B.P. (GSC 2004, Lowdon et al. 1977) from Sulphur Lake east of the Clear Hills. The latter site lies west of the late Clayhurst stage ice limits. However, both dates may have a carbonate error.

Mathews (1980:19) has concluded that the Clayhurst Stage ended prior to 10,000 years B.P. It is suggested here that the minimum age for the end of that stage is 10,400 years B.P., plus whatever time would have been required for the development of extensive periglacial features. There is no good time estimate for the formation of prairie mounds, but pingo formation could take hundreds of years (Bik 1969). If this chronology is correct, extensive areas of glaciolacustrine sediment would also have been exposed to plant colonization by the herbaceous chenopods, sages, grasses and sedges which were the early colonists of the Boone Lake basin prior to 11,700±260 years B.P.

A problem may arise if one attempts to make a correlation between the deglaciation of the Peace River area and the deglaciation of southern Saskatchewan. The late Clayhurst or Indian Creek Stage of Mathews (1980) appear to correlate with St. Onge's Phase 6 (St. Onge 1972). St. Onge (1980) has indicated that his Phase 6 correlates well with Christensen's Phase 6 in the deglaciation of Saskatchewan, at which time the southern half of the province was ice-free, and which he dated at 12,000 years B.P. However, Clayton and Moran (1982) show ice cover over all but the southwestern portion of Saskatchewan at 12,300 years B.P., arguing that this is a firmly dated event. Teller *et al.* (1980) also argue that Christensen's radiocarbon dates are too old due to reworked carbon contamination.

The above interpretation of the recession of Glacial Lake Peace could fit easily into Christensen's chronology. However, if Clayton and Moran's chronology is correct, there might still just be sufficient time after 12,300 years B.P. for ice to melt from the southern half of Saskatchewan, for the proglacial pondages to drain in the Peace River area, and for periglacial activity to take place prior to 10,400 years B.P.

Significance for Early Man

The work of Mathews (1978,1980) and this study allow a definitive rejection of Reeves (1973) argument that the Ice-free Corridor was blocked only at the Athabasca Valley between 20,000 and 18,000 years B.P. in the last 55,000 years. The ice blockage of the Peace River area took place some time after about 26,000 years B.P.

Haynes (1971) has noted that a corridor would have had to exist prior to 11,500 years B.P. to be of use in explaining the arrival of Clovis culture on the Great Plains. Fladmark (1979,1981) has further raised the question of the habitability of any corridor, emphasizing glacial lakes and katabatic winds as formidable obstacles for early man.

One can not draw conclusions about the whole northern section of the corridor from the present data. The conclusions must be confined to the Saddle Hills and immediate vicinity.

Ablation of the ice mass which fed meltwater to Boone Lake was complete by 11,700±260 years B.P., and an open deciduous tree - shrub herb flora capable of supporting some fauna was established at least by that time. This suggests a habitable, local ice-free area. Nonetheless, the significance for early man studies is equivocal. One could set 11,600 years B.P. as a minimum time for the corridor to have been in existence to allow possible early migrants to travel to the southern plains by 11,500 years B.P. It can then be stated that the probability is .63 that the real age of the 11,700±260 year date is ≥11,600 years B.P. and ≤12,220 years B.P.

The minimum age proposed in this study for the drainage of the major proglacial lakes also can only indicate that any migrating people might, or might not have had to contend in summertime with extensive meltwater lakes.

Gravity winds off the ice masses would appear not to have been a problem to man by the time of the recession of the Indian Creek Stage of Glacial Lake Peace (Mathews 1980:Figure 5F). Henderson's (1959) Lake Fahler can be correlated with Mathews' late Clayhurst or Indian Creek Stage. Henderson (1959:78-80) observed dune patterns of the Watino-map area, formed after Lake Fahler's drainage. He concluded that storm winds and prevailing winds were from the west at that time, and that gravity winds from the ice were of no local significance.

In summary, it can be argued that there is a 63% probability of a local Ice-free Corridor between 11,600 and 12,220 years B.P., if one assumes that deglaciation and revegetation occurred in the rest of the Peace River district at the same time as it did in the southern Saddle Hills.

B. The Postglacial Record

Two comparable records of Holocene vegetation and climatic change in the Saddle Hills were derived from pollen analyses of gyttja sediments of Boone and Spring Lakes. The Boone Lake core was used for the most detailed analysis. The Spring Lake core served to test the patterns derived from Boone Lake, to determine whether they should be interpreted as regional or local events.

The following data on regional climate and vegetation, and the vegetation surrounding the two lakes aids in the interpretation of the Holocene records.

I. Regional Climate

Climatic average statistics for the Saddle Hills - Grande Prairie area, derived over a 1931-1961 observation period are summarized by North (1976:Fig 4-6): January mean temperature, -15° C; April mean temperature, 2° C; July mean temperature, 16° C; October mean temperature, 4° C; mean annual precipitation, 43 cm; mean precipitation April 1 to September 30, 28 cm. The average moisture deficit observed from 1921 to 1950 was 15 cm, computed for loamy soil with a 10 cm storage capacity. Twenty five percent of the years experienced more than a 20 cm moisture deficit during the same observation period.

II. Regional Vegetation

The primary vegetation studies in the upper Peace River region have been carried out by Raup (1934) and Moss (1952, 1953a,b). Ferguson (1980) has contributed to the study of Native burning practices, and Wilkinson (1981) has studied the soils of the Peace River grasslands.

According to Rowe's (1972) summary of Canadian forest regions, the Saddle Hills are covered by Lower Foothills forest. *Pinus contorta* (lodgepole pine), with *Populus tremuloides* (trembling aspen) and *Populus balsamifera* (balsam poplar) have dominated the area because of repeated fire. *Picea glauca* (white spruce) is important in older stands and *Picea mariana* (black spruce) is frequently present. *Betula papyrifera* (white birch) is present on well drained sites, and tamarack on poorly drained sites. *Abies lasiocarpa* (alpine fir) and *Abies balsamea* (balsam fir) are common. Surrounding the Saddle Hills to the north, east and south is Mixedwood Forest. White spruce and balsam fir are most common in old stands. The greatest areal coverage is of aspen, balsam poplar, white birch and *Betula neoalaskana* (Alaska birch). Black spruce and *Larix laricina* (tamarack) muskeg occur in water-catchment areas. Just south and northeast of the Saddle Hills are areas of aspen grove, which were interspersed with patches of prairie and meadow that have mostly disappeared under agriculture.

Moss (1952, 1953a,b) has described the vegetation of northwestern Alberta in greater detail using the concepts of association and climax. He characterizes the vegetation as transitional between cordilleran and boreal, and boreal and grassland (1953a). His studies of upland vegetation are summarized below. Species names have been altered to conform to Taylor and MacBryde (1977).

According to Moss (1953a), the white spruce associatation is prevalent and well defined. This association crosses the boreal - cordilleran transition, occuring with balsam fir in the east and lodgepole pine in the west. There are 4 faciations. Young, dense stands are the needle-cover faciation. In the grass-shrub faciation white spruce occurs with Elymus innovatus, Aster conspicuus, Shepherdia canadensis, and Alnus viridis. The shrub-herb faciation includes Viburnum edule (highbush cranberry), Rosa spp. (rose), Ribes spp. (currants), Linnaea borealis, Rubus pubescens, Mertensia paniculata, Fragaria spp., Pyrola spp., Epilobium angustifolium, Calamagrostis canadensis, Cornus canadensis, Mitella nuda, Viola renifolia and Petasites palmatus. There are mixtures of aspen and balsam poplar, willows and paper birch. A feather moss faciation has continuous cover of Hylocomium splendens and other mosses. White spruce is considered to be the climax species on mesic sites in northwestern Alberta.

Two black spruce associations were defined, a black spruce - Hylocomium splendens association, and a black spruce -

Sphagnum association, the former in shallow depressions and the latter in deep depressions.

A tamarack association is characterized by a single tree dominant, occuring with a variety of shrubs and herbs.

Balsam fir occurs occasionally in local pure stands, and in mixed stands of spruce, aspen, poplar, and birch near Lesser Slave Lake. Moss (1953a) notes the possibility of hybridization with alpine fir.

The eastern ranges of interior lodgepole pine, Pinus contorta var. latifolia, and Pinus banksiana (jack pine), overlap in the Peace River area and there is hybridization. Both pines are usually found on sandy and gravelly areas, but lodgepole pine occurs also on heavier soils in its range. Moss (1953a) defines a jack pine and a lodgepole pine consociation, each with two faciations. The pine - feather moss faciation is characterized by Hylocomium splendens and Calliergonella schreberi. The pine - heath faciation is characterized by Arctostaphylos uva-ursi and Vaccinium vitis-idaea, grasses and mosses. Alnus viridis (American green alder), roses, Salix spp. (willows), and Maianthemum are common to both faciations. Pines are seral trees following fires.

Moss (1953a) also defines a poplar association, with an aspen and balsam poplar consociation.

The balsam poplar consociation occurs especially on moist river flood plains with a small tree - shrub layer of willow, Cornus sericea (red-osier dogwood), Alnus incana (mountain alder), roses , and other shrubs and herbs.

Trembling aspen is the most common tree in the region, occuring in pure stands or mixed with other trees in many edaphic conditions. The aspen consociation has a discontinuous small tree-shrub stratum of *Salix bebbiana* (Bebb's willow), red-osier dogwood, *Amelanchier alnifolia* (common saskatoon). The low shrub stratum is characterized by *Rosa acicularis* (prickly rose), *Rosa woodsii*, (Woods' rose), highbush cranberry, *Symphoricarpos alba* (common snowberry), soapberry, *Rubus idaeus*, and *Ribes oxyacanthoides*. The successional trend from aspen to spruce is counteracted chiefly by fire.

Peace River grasslands

The Peace River grasslands have been the subject of considerable botanical interest. The early white travelers through the Peace River found extensive tracts of native grassland, interspersed with aspen copses, in areas which virtually surround the Saddle Hills (Moss 1952:Figure 1). The Spirit River prairie, to the northwest, was 2330 km², and 80% open. The northern edge of the Grande Prairie was only 12 km south of Boone Lake, and it covered 24,000 km², 85% of which was open (Wilkinson 1981). Moss (1952) also shows extensive prairies in and north of the Pouce Coupe - Dawson Creek area.

Moss (1952) categorized the entire grassland as an *Agropyron* - *Stipa* - *Carex* community, excluding grass and sedge wetland communities. Three faciations make up this community.

The *Agropyron* - *Carex* faciation occurs on low, moist flat areas in the northern prairies. The *Stipa* faciation occurs on dry, south-facing slopes especially along the Peace River, and it intergrades with the *Agropyron* - *Stipa* faciation. The *Agropyron* - *Stipa* faciation is the most prevalent, occupying moderately dry slopes and flats and is the climax, or the edaphic climax grassland for the region. *Agropyron trachycaulum*, *Stipa spartea* var. *curtiseta*, *Koeleria cristata*, *Carex obtusata*, *Galium boreale*, *Achillea millefolium* and *Thalictrum venulosum* are the most constant and characteristic species of this faciation. *Symphoricarpos occidentalis* (western snowberry), roses, and common saskatoon are characteristic shrubs of the *Agropyron* - *Stipa* and *Stipa* faciations.

Wilkinson (1981) has recently defined a *Carex* - *Danthonia* - *Stipa* community type, equivalent to Moss' (1952) *Agropyron* - *Stipa* faciation, and a *Stipa* - *Carex* - *Artemisia* community type equivalent to Moss' *Stipa* faciation. In Wilkinson's former community type grasses are 44% of the cover, while in the latter community type grasses are 57% of the cover (derived from Wilkinson 1981:Table 1). Herbs and shrubs are thus important grassland elements.

The origin of the Peace River grasslands has been a question of longstanding botanical interest. Their development was attributed by Raup (1934,1935) to succession from tundra through subarctic grass and sedge stages, and he also notes the possibility that they are relics of a once more northerly extension of the main grasslands of Alberta (1941). Hansen (1952) also suggested that the Peace River grasslands could have been areas of persistent grassland from much more extensive xerothermal period grasslands, yet notes in the same paper that there is no palynological evidence of previously more extensive grasslands. Moss (1952) accepts the climatic hypothesis as worthy of consideration, but also emphasizes edaphic factors and fire for the persistence of the prairies. Odynsky _et al._ (1961) noted the coincidence of Peace River parklands and fine textured, saline soils with a hardpan. Wilkinson (1981) has shown a general correlation between Peace River grasslands and solonetzic soils, although soil analysis did not show statistically significant differences between soils under former prairies and former forested sites. Wilkinson cites a high variability of solonetzic soils, and post-settlement factors such as fertilizer application and drainage, as possible factors masking former soil differences. Wilkinson (1981:50-52) concludes that solonetzic soils could inhibit aspen invasion, but that fire could augment aspen suckering and invasion of the grassland. On the other hand, Ferguson (1980:69) considers native burning to have been a major factor in the maintenance of prairies in the Lower Peace region. North (1976:46) has suggested that if the proglacial lakes were drained during the Hypsithermal, the loose, shifting sediments would be colonized by grasses. Occasional drought and spring flooding would further inhibit tree growth.

The origin of the Peace River grasslands emphasizes several important considerations for regional palaeoecology - the timing of withdrawal of the proglacial lakes, the nature of vegetation development during and after deglaciation, and the local effect of the Hypsithermal interval on grassland and upland forests.

Boone Lake and Spring Lake area forest cover

The forest cover of an area 4.83 km² (3 mi.²), or 23.3 sq. km (9 sq. mi.) centred on Boone Lake was assessed using Alberta Energy, Mines and Resources Forest Cover Series Sheet 83M NW (Saddle Hills). The following are the percentages of cover types: scrub - 29%; pine and deciduous - 17%, deciduous - 15%; pine, white spruce and deciduous - 12%; deciduous and white spruce - 11%; pine and spruce - 11%; potentially productive land - 3%; pine - 1%; bog or muskeg - 1%. The scrub area surrounds Boone Lake on the southeast, south, and west sides. Much of the area classified as scrub is bog, on which glandular birch, willow, and black spruce are important cover (Moss 1953b).

Homesteads with about .75 km² of cleared land existed 1.5 km southwest of Boone Lake. Odynsky (1961) indicates that these lands were abandoned before 1961.

Forest cover of an area 4.83 by 4.03 km (3 by 2.5 mi.), or 18 km² (7.5 mi.²) centred on Spring Lake was assessed using the Saddle Hills Forest Cover Series and aerial photographs. The results are: deciduous cover - 60%; potentially productive land - 14%; brush or old burn - 12%; deciduous and white spruce - 7%;

coniferous - 7%. The classification of deciduous cover is probably mostly aspen with some cottonwood and an understory of willow and lower shrubs. Brush and old burn is probably willow and aspen with other lower shrubs. Potentially productive land is valley sides and bottom with scrub vegetation.

III. Pollen and Sediment Analysis

Sediment description

In order to provide the most complete postglacial record, BLA below the clay band at 4.90 m and BLB above the clay band were combined to give a core designated BLA,B. Except for the clay band, the BLA,B composite core was continuous gyttja with some macrofossil remains (Figure 10).

Time was controlled using 6 radiocarbon dates (Figure 11). The basal clay - gyttja transition was dated at 11,700±260 years B.P. using SFU 223 (poplar wood) from BLD. All other radiocarbon dates came from sediment in BLA,B. Figure 11 shows depth plotted against age, with a line hand fitted to reduce the magnitude of changes in sedimentation rate. The calculated deposition rate at the clay band is much slower than in any other part of the core, which might indicate a short sediment discontinuity.

The Spring Lake core is made up of the upper metre of sediment from SLB, taken in a clear plastic barrel, and the SLA core below 1 m. Figure 12 shows SLA,B which is gyttja, discontinuously laminated below 2.00 m and continuously laminated below 4.00 m to the clay - gyttja transition. The laminae are very thin and impossible to separate for individual analysis. They range from dark and light brown to light grey. Microscopic examination showed that they are predominantly organic matter, and one dark band examined appeared to contain a substantial amount of charcoal. Some of the light bands effervesced in 10% HCl more than other laminae, but this was not consistent. It is likely that the laminae represent short periods of deposition, perhaps of one or more years, but they are apparently not consistently annual rhythmites.

Standard physical analysis (Bengtsson 1979) was done on SLA,B. The bulk density (D.),dry weight (D.W.) and loss on ignition (I.L.) analyses (Figure 13) clearly show the transition from gyttja to clay below 4.40 m. Bulk density and D.W. drop gradually above 4.40 m, probably showing decreased sediment compaction. There is a gradual decline in I.L., with a distinct decline in the upper metre, but the significance of this variation is unknown.

Chronological control for SLA,B is provided by 4 radiocarbon dates from Spring Lake (Figure 11,12). The lower two dates were obtained from the SLB core. The clay - gyttja transition is used as a stratigraphic marker to transfer the dates to SLA. The other dates were obtained from SLA sediment.

Additional chronological control for SLA,B is provided by transferring SFU 206 , the date of the pine peak in BLA,B core, to SLA,B.

Figure 11. Boone Lake A,B and Spring Lake A,B cores ^{14}C dates plotted against sediment depth.

SEDIMENTATION RATES

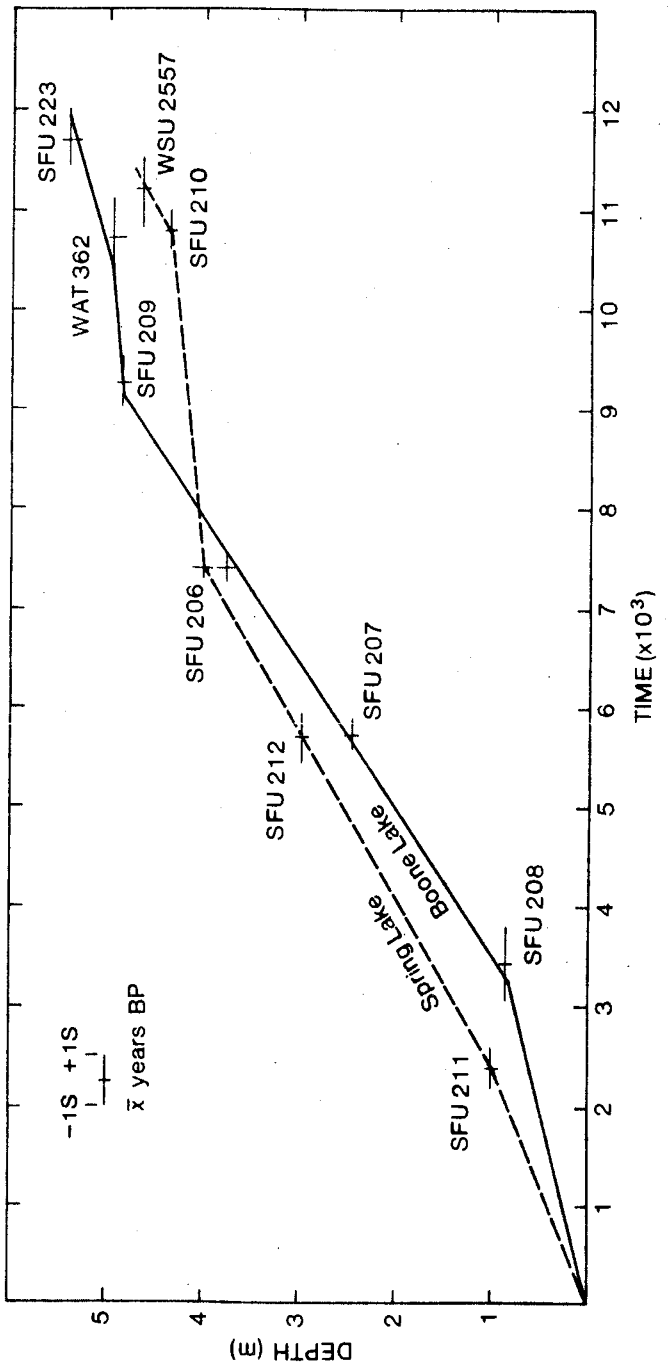
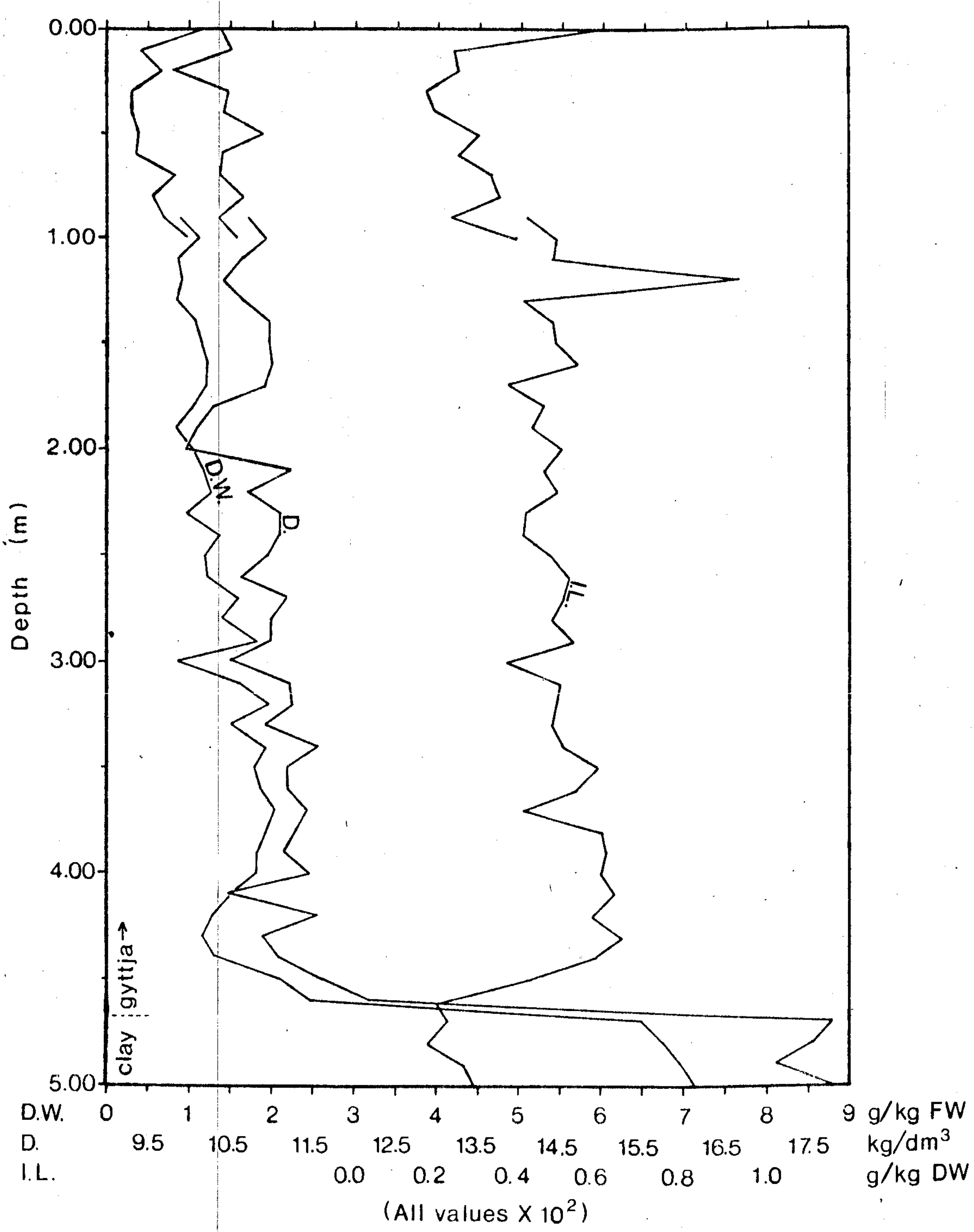


Figure 13. Bulk density (D.), dry weight (D.W.), and loss on ignition (I.L.) analyses of Spring Lake core A,B.



D., Bulk density (kg/dm^3) D.W., Dry weight (g/kg of Fresh Weight) I.L., Loss on ignition (g/kg of Dry Weight)

Pollen analysis

One ml subsamples were taken from the cores, normally at 5 cm intervals. The samples were processed by standard HCl, KOH, HF, and acetolysis techniques (Faegri and Iversen 1975), and mounted in silicone oil (Anderson 1960). Slides were systematically scanned until an upland sum of about 500 grains was obtained. In the early postglacial levels, lower sums were accepted.

The emphasis of this study was to detect long-term, regional trends. A skeleton diagram at 15 cm intervals was prepared for Boone Lake to detect the period of greatest vegetation change. The section of core below 3.00 m was subsequently analysed at 5 cm, or closer intervals. Only minor long-term trends were seen in the upper 3 m of Boone Lake, so the skeleton diagram was considered satisfactory. Spring Lake was analysed by skeleton diagram at 10 or 15 cm intervals to corroborate trends and regional patterns detected in Boone Lake.

In Boone Lake the analysis interval between the sediment surface and .85 m was 15 cm, equivalent to 580 years between analyses. Between .85 and 3.00 m the analysis interval was 15 cm, equivalent to 220 years. Below 3.00 m the interval was 5 cm, equivalent to 75 years (excluding the clay band). Below 5.06 m the interval was 3 cm, equivalent to 100 years. Thus, the analysis emphasized the period of greatest vegetation change in the early postglacial period.

In Spring Lake the analysis interval was generally 15 cm, and someplaces 10 cm from the surface to 4.00 m. This was equivalent to 365 year intervals from the surface to 1.00 m, and at most 250 year intervals from 1.00 to 3.00 m. Below 4.00 m the analysis interval was 5 cm, equivalent to 450 year intervals below 4.00 m and 140 year intervals below 4.40 m.

Pollen identification

Pollen was identified using standard keys (Faegri and Iversen 1975, Kapp 1969, McAndrews *et al.* 1973) and a reference collection. The potential flora of the region was defined using *Vascular Plants of British Columbia* (Taylor and MacBryde 1977), the *Flora of Alberta* (Moss 1974), and Moss (1952,1953a,b).

Abies lasiocarpa is found in the subalpine west of the study area, and *A. balsamea* reaches its western limit in the study area (Hosie 1973), although there is the possibility of hybridization (Moss 1953a). Reference pollen for *A. lasiocarpa* was found to be much larger than *A. balsamea*, but the taxa were not separated following Kapp's (1969) caution.

Picea glauca and *P. mariana* have been shown to be separable by discriminant analysis (Birks and Peglar 1981). Eleven spruce grains from the early postglacial 5.24 m level of Boone Lake, which were undamaged and presented in equatorial view were classified by discriminant analysis. All grains were classified as white spruce, being greater than the discriminant index, and only one grain fell within the possible range of values of black spruce. It is therefore concluded that the early postglacial population of spruce included a high proportion of white spruce.

Pinus contorta and *P. banksiana* both have diploxylon type pollen (Ting 1965, McAndrews 1973), and no attempt was made to separate the two taxa.

Indeterminate vesiculate grains were saccate grains too crushed or torn to identify.

Alnus incana and *A. viridis* occur in the Boreal White and Black Spruce zone (Taylor and MacBryde 1977). No attempt was made to separate the pollen.

Several tree and shrub birches occur in the Peace River district, *Betula papyrifera*, *B. neoalaskana*, *B. occidentalis* and *B. glandulosa* (Hosie 1973, Krajina *et al.* 1982).

Individual separation of the pollen of these species was not attempted. Equatorial diameter and diameter/pore depth ratios have proven useful elsewhere for separating birches, (Birks 1968), but the technique has not been systematically applied in northwestern North America. However, the simple equatorial diameter of grains has also been used to detect shrub or tree birch predominance (Ritchie 1977,1982; Cwynar 1980).

In this study birch equatorial diameters were measured on 1638 fossil grains presented in polar view in BLA,B. The distribution of the mean, standard deviation, and sample size per level is shown in Figure 14.

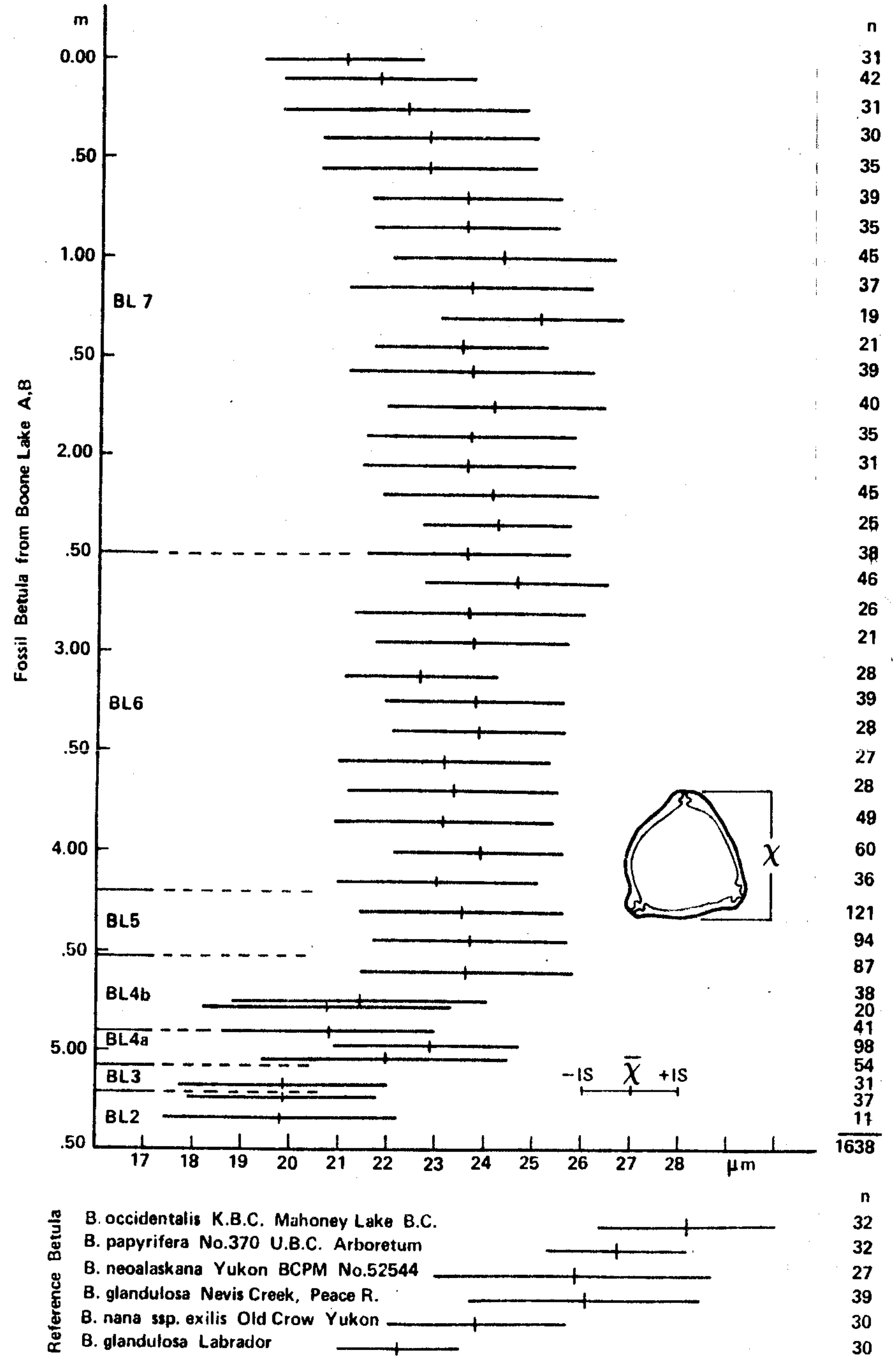
Measurements of *Betula* reference collections are shown in Figure 14. All birch reference material was processed by NaOH or

KOH and acetolysis, and was mounted in silicone oil, which does not cause long-term size changes (Anderson 1960). Coverslip supports were not used (Cushing 1961) but the grains were apparently not crushed under the coverslips. A size gradation is evident, with the shrub birches tending to have smaller grains than the tree birches. Only *B. nana* and a Labrador sample of *B. glandulosa* show clear size separation from *B. occidentalis* and *B. papyrifera*. *B. neoalaskana* and the Nevis Creek sample of *B. glandulosa* are intermediate in size, with a very large standard deviation. The two *B. glandulosa* collections are surprisingly distinct. The ability of birches to hybridize probably contributes to this difficulty in separation.

The fossil collections' mean sizes are distinctly smaller than the reference collection sizes. Even the surface sample, which must contain a mixture of pollen of all birch species in the region, has a mean size smaller than any reference material. Likewise, the sizes for shrub birch pollen from the reference collections are large in comparison with Cwynar's (1980) data from Hanging Lake, northern Yukon. Here a mean of 19-20 micrometers is found from the surface sediment sample, which must consist mostly of the regional species *B. glandulosa* and *B. nana* ssp. *exilis*.

The overlap of reference pollen sizes and the size difference between modern and fossil populations shows the difficulty of making unequivocal conclusions from *Betula* grain size distributions. There is nonetheless a tendency for shrub

Figure 14. Distribution of fossil and reference <u>Betula</u> pollen grain size measurements.


m
0.00
.50
1.00
.50
2.00
.50
3.00
.50
4.00
.50
5.00
.50
Fossil Betula from Boone Lake A,B
BL 7
BL6
BL5
BL4b
BL4a
BL3
BL2
n
31
42
31
30
35
39
35
45
37
19
21
39
40
35
31
45
25
38
46
26
21
28
39
28
27
28
49
60
36
121
94
87
38
20
41
98
54
31
37
11
1638
X
−IS
X̄
+IS
17
18
19
20
21
22
23
24
25
26
27
28
µm
Reference Betula
B. occidentalis K.B.C. Mahoney Lake B.C.
B. papyrifera No.370 U.B.C. Arboretum
B. neoalaskana Yukon BCPM No.52544
B. glandulosa Nevis Creek, Peace R.
B. nana ssp. exilis Old Crow Yukon
B. glandulosa Labrador
n
32
32
27
39
30
30

birch to be smaller than tree birch pollen.

Certain trends appear in the BL data. The variations in the mean size of the grains likely represent changes in the proportion of shrub and tree birch pollen in the Betula pollen sum. The birch size trends suggest that shrub birch predominated in the lowest three levels. Tree birch types rapidly became a larger proportion of the total, but a short trend towards shrub birch type began above 4.95 m. By 4.60 m tree birch type pollen was again relatively abundant. Little change is noted up to 1.00 m, at which point the relative abundance of shrub birch type again begins to increase.

Populus pollen could come from trembling aspen or balsam poplar. Poplar pollen is notoriously susceptible to corrosion (Havinga 1964, Sangster and Dale 1961). Its consequent underrepresentation in the fossil pollen spectra is illustrated by its extremely low value, or absence, in the sediment surface samples of Spring Lake and Boone Lake, although aspen is a major component of the regional upland vegetation. This extreme underrepresentation is a significant problem for boreal palaeoecology. Aspen is a seral species like pine, and the presence of pine has been used previously to suggest the presence of aspen (White and Mathewes 1982). Populus pollen often occurs in abundance in late Pleistocene pollen spectra (Mott 1978), as it appears in this study. While its aggressive modern habit suggests that it is a likely invader of newly deglaciated terrain , the abundant representation in the early pollen spectra suggest that postglacial sedimentary conditions were important to its preservation. Populus is much better represented in the reduced sediments of Spring Lake, deposited in the anoxic hypolimnion, than in the sediments of shallower Boone Lake. The early Holocene decline of poplar in the sediment of Spring Lake thus indicates that it represents a change in forest composition, rather than just changes in the lacustrine environment. The poplar grains identified are generally crushed and corroded, and there is the possibility of confusion with crushed and corroded sedge grains. Levels in the core where poplar and sedge are abundant thus have high percentages of undeterminable pollen. Poplar wood, identified and dated at 11,700±260 years B.P. in BLD was from the clay-gyttja interface, equivalent to the same interface in BLA,B, where poplar pollen is relatively abundant.

Viburnum is likely V. edule, a common member of the low shrub stratum of the aspen consociation and of the white spruce association (Moss 1953a).

Myrica gale and Corylus cornuta occur in the BWBS zone (Taylor and MacBryde 1977) but Corylus is rare, being more common in central Alberta (Moss 1953a). Edwards (1981) has shown the unreliability of separation of these taxa in Europe by light microscopy. Although separated, the taxa have been designated as Myrica type and Corylus type.

Shepherdia canadensis can occur in the Peace River area under white spruce, lodgepole pine, and aspen dominants (Moss

1953a). It has nitrogen-fixing endophytes (Bond 1967) and is an aggressive colonizer in the late-glacial (Mathewes 1973) .

Many species of *Salix* occur in the Peace River area (Brayshaw 1976). Most are found in wet habitats, but *Salix bebbiana* is a common upland willow (Moss 1953a).

The key for the separation of *Artemisia* by Bassett *et al.* (1978) was found to require observation beyond that possible with the Nikon SkT microscope. *Artemisia dracunculus*, *A. frigida*, *A. longifolia*, and *A. ludoviciana* have been observed on steep, eroded slopes in Silver Valley on the south side of the Peace River about 60 km north of Boone Lake (Lee and MacIsaac 1981).

A small tricolpate grain with a reticulum visible at x1000 compared well with *Descurainia*. *D. pinnata* and *D. richardsonii* occur in the Boreal White and Black Spruce zone (Taylor and MacBryde 1977), and in Alberta (Moss 1974). Moss (1974) indicates that the habitat is dry slopes and denuded places.

The Poaceae have been included in the upland sum in the pollen diagrams. *Stipa* and *Agropyron* are important modern genera (Wilkinson 1981:Table 1, Moss 1952). Nonetheless, there are emergent grasses such as *Calamagrostis* spp., *Poa* spp., and *Agrostis spp.* (Moss 1953b) which could contribute grass pollen directly to the lake.

The Cyperaceae have been placed in the aquatic sum, commonly being emergents. However, the Cyperaceae are also important modern upland elements (Moss 1952, Wilkinson 1981), and in the early postglacial sedge pollen could have originated from upland colonizing plants as well as from emergent plants. However, after forest developed it is likely that most of the sedge pollen originated from emergent plants.

Rumex type includes *Rumex* and *Oxyria*. *Rumex acetosa* and *R. arcticus* presently occur in the Boreal White and Black Spruce zone (Taylor and MacBryde 1977). The alpine *O. digyna* is not likely the species represented.

Pollen diagrams

Pollen percentage and influx diagrams were generated using a Polldata Mk. IV program, written at Cambridge Univesity by H.J.B. Birks and Brian Huntley, and modified for operation at Simon Fraser University by J. Little and D. Wilson.

All upland taxa are included in the pollen sum, while the taxa which are commonly emergents and aquatics are calculated outside the sum. The number of taxa in the sum is written in a column immediately to the right of the pollen sum.

IV. Numerical and Statistical Techniques

Test for randomness of distribution of a taxon

The significance of the distribution of taxa which have low and sporadic representation through time is often unclear to palynologists. It is difficult to decide by visual inspection whether there is a significant clustering of a taxon in a particular core segment, or whether the observed distribution might result from random encounters of a rare taxon whose percentage was nonetheless equal amongst all those populations of pollen grains sampled.

A nonparametric test, the One-Sample Runs Test (Siegel 1956) has been employed to determine the probability that the distribution of some taxa in the Boone Lake and Spring Lake percentage diagrams is due to random draws from homogeneous populations. Taxa represented by '+' (<.5%) or very low histogram bars on the pollen diagrams, whose distributions suggested some clustering, were selected for statistical analysis.

As the One-Sample Runs Test uses ordinal data, a single high percentage occurrence, such as Equisetum in BLA,B, must be converted to a '+', with a consequent loss of information. The Komolgorov - Smirnov goodness of fit test (Siegel 1956) is more appropriate for such data. The One-Sample Runs Test should be applied to taxa whose representation can be converted to presence/absence data without a great information loss.

The punched output suitable for numerical zonation from the Polldata Mk IV program by H.J.B. Birks and Brian Huntley is appropriately arranged for the determination runs. 'Z' can be solved for rapidly by a programmable calculator.

Calculation of 'z' and reference to tabular values for 'p' under a normal distribution give probabilities for values as extreme as the observed 'z'. The test may be one- or two-tailed. In the latter case the table values for 'p' are doubled. Usually a test would be used to ascertain whether there was a significant clustering of a taxon in a certain core segment. This is equivalent to a one-tailed alternate, that there were fewer runs in the data than one would expect to observe under the null hypothesis. Thus the one-tailed probability can be used. Alternatively, some pattern of recurrent increase in the population of a taxon might produce more runs than would be expected under a null hypothesis. A one-tailed probability would also be used.

Table 1 and 2 give the one-and two-tailed values for 'z' for the taxa tested in SLA,B and BLA,B. Taxa for which the distributions are significant at .05 (*) or .01(**) for a one- or two-tailed alternative are marked on Tables 1 and 2.

Table 1: Probabilities of random distribution of various taxa in Boone Lake cores A,B.

TAXON	Z	ONE-TAILED	TWO-TAILED
Viburnum	-3.28	<.00007**	**
Cornus sericea	+0.28	.3897	.7794
Corylus ty.	-7.00	<<.00003**	**
S. canadensis	-1.71	.0436*	.0872
Rosaceae	-2.16	.0154*	.0308
Apiaceae	-0.97	.1660	.3320
Caryophyllaceae	+0.65	.2578	.5156
Chenopodiineae	-1.86	.0314*	.0628
Thalictrun	+0.47	.3192	.6384
Lycopodium	-2.07	.0192*	.0384

Table 2: Probabilities of random distributions of various taxa in Spring Lake cores A,B

TAXON	Z	ONE-TAILED	TWO-TAILED
Viburnum	-3.18	.0007**	.0014**
Cornus sericea	-1.24	.1075	.2150
Corylus ty.	-2.50	.0062**	.0124**
S. canadensis	-1.22	.1112	.2224
Myrica ty.	+0.13	.4483	.8966
Rosaceae	-0.68	.2483	.4966
Chenopodiineae	-2.67	.0038**	.0076**
Thalictrum	-1.24	.1075	.2150

This approach is one of data analysis only. It is necessary to test the significance of observed distributions on a pollen diagram before assigning any palaeoecological significance to the data.

Three taxa *Viburnum*, *Corylus* ty., and Chenopodiineae have significant distributions in Boone and Spring Lakes. All have fewer runs than would be expected under the null hypothesis.

The Chenopodiineae are shown in the pollen percentage diagrams from Boone and Spring Lakes (Figures 11,13) to occur mostly in the lower half of each diagram, with a strong presence noted in the basal zones, BL2 and SL1.

Corylus ty. also shows a clustering towards the base of the diagram in SL1 and SL2, and in BL3 and BL4a.

Viburnum's clustering pattern is not consistent, being in BL3 and BL4 before 8700 years B.P., but in SL3 after 8200 years B.P.

Shepherdia clustering occurs in BL2 to BL6 and in SL1 to SL3. If percentage representation in BL2 to BL4 and in SL1 were considered by another statistical technique, the significance values could be much higher.

Rosaceae clusters in zones BL2 and BL3, and *Lycopodium* clusters in BL4b.

Confidence intervals for percentage data

The Polldata Mk IV program generates .95 confidence intervals for percentages of all taxa where at least one value ≥2.5%. Calculations are based on a confidence interval for a binomial distribution (Mosimann 1965, Maher 1972). The Polldata Mk IV program has been modified at Simon Fraser University by Mr. Douglas Wilson so that error bars are added to the plotted histograms to indicate the width of the calculated confidence interval (Figures 10,12).

If the calculated point percentage value of a taxon at one level is included in the 0.95 confidence interval of another level, the taxon proportions will not be found to differ at the 0.05 level. If the calculated point percentage values of a taxon in two sample levels are not included in each other's confidence interval, the taxon will usually be found to differ between the two samples at the 0.05 level of significance (Maher 1972).

Numerical zonation

The numerical zonation of Boone Lake and Spring Lake percentage diagrams (Figures 10,12) was generated using a program described by Birks (1979) and Gordon and Birks (1972). The taxa spruce, pine, alder, birch, poplar, willow, sage, *Equisetum*, Chenopodiineae and grass were used for numerical zonation as they were each represented at least once by a value of >5%.

The results of SPLITINF and SPLITLSQ were plotted to the point at which an additional marker reduced the residual variation by 2% or less. It was judged that further division of the diagram would yield a multiplicity of subzones with little increase in the understanding of the diagram.

The results of SPLITINF and SPLITILSQ were used to guide the zonation of the diagram, and zone boundaries were drawn where these two routines indicated a subdivision at the same, or almost the same point.

CONSLINK was not considered as useful for the selection of zonal boundaries. However, it clearly shows in what sections of the diagram substantial change takes place from level to level, which are those segments where spectra are united at a high level of dissimilarity.

V. Pollen Zonation

Boone Lake

BL1 has been described above in Part A. The following discussion refers to the Boone Lake pollen percentage diagram (Figure 10) and influx diagram (Figure 15).

BL2 (5.40 to 5.24 m; ca. 11,700 to 11,500 years B.P.) is a deciduous tree - shrub - herb zone. Poplar and willow are highly represented. Soapberry is consistently represented at about 3%. The birch are largely dwarf types, probably glandular birch. Sage, other Tubuliflorae, Chenopodiineae and grasses are well represented. Aquatic or emergent species include abundant sedge and *Myriophyllum*, *Potamogeton*, and *Typha*. The high undeterminable sum represents eroded poplar and sedge grains which could not be clearly separated. The total pollen influx is low, less than 1100 grains cm^{-2} $yr.^{-1}$.

Macrofossil analysis above the dated poplar wood in BLD additionally indicates the presence of *Ceratophyllum demersum*, bryophytes, *Chara*, 3 species of gastropods, ostracods, and *Daphnia*. The poplar wood confirms the presence of poplar pollen, and sedge and *Potamogeton* achenes also appear with their pollen in these zones.

BL3 (5.24 to 5.06 m; ca. 11,500 to 11,200 years B.P.) is characterized by tree - shrub - herb spectra. Spruce (mostly white spruce) rises to >10% and pine to >20% in BL3. However, the influx values do not show significant increase from BL2. Birch and alder rise in percentage and a little in influx. The grain size distribution of birch suggests increased presence of tree birches. The steep percentage decline in poplar and willow is likely an artifact of the increase in the other taxa, as the influx decreases are less marked. The shrub pollen from highbush cranberry and Corylus type show a highly significant clustering in BL3 and in the lower part of BL4. The probability associated with Rosaceae distribution (Table 3) argues for some clustering in BL3. Chenopodiineae have declined somewhat in percentage and influx values, which remain little changed in subsequent zones until BL7. Grass percentage and influx increases, and sedge declines. Sage and Myriophyllum both declined in relative importance without noticeable influx change. Typha shows percentage and influx increase. The total influx rose to ≥1000 grains cm^{-2} yr^{-1}.

In BL4 (5.06 to 4.54 m; ca. 11,200 to 8700 years B.P.) the conifers have high influx and percentage values. The gyttja in BL4 is interrupted by a clay band at 4.92 m, and the ^{14}C dates show the slowest accumulation rate in the core in the centre of this zone, 112 yrs. cm^{-1}. Two of the numerical zonation programs have isolated this zone as a relatively homogeneous unit, yet the clay band and SPLITINF indicate a subdivision into BL4a and BL4b at 4.90 m.

Fir is continuously represented in the core beginning in BL4a. Spruce and pine have significant percentage and influx peaks and declines in BL4a. Birch shows a rise in total pollen and in the percentage of tree pollen, terminating in a sharp drop in total percentage and in the proportion of tree types. Poplar percentages and influx are as low as in BL3. Other taxa percentages are low in response to the rise in tree pollen, but show no influx changes from the lower zones.

BL4b starts at 4.90 m, estimated to be 10,000 years B.P. Conifer percentages and influx show a significant increase after the previous decline. Alder, willow, and grass show percentage and influx increase, while a sage increase is apparent in percentage only. A notable feature of BL4b is the initial low percentage and influx of birch, with a gradual rise during the zone. The birch grain size distribution suggests that the tree types increased in proportion during the zone. Though _Populus_ shows a sharp percentage increase at the base of the zone, it is not confirmed in influx. A distinct _Equisetum_ peak follows the clay band. Possibly _Equisetum_ was colonizing eroded mineral soils. _Lycopodium_ also shows a distinct clustering in this zone. Influx in BL4b rises to >6000 grains cm^{-2} $yr.^{-1}$.

BL5 (4.54 to 4.20 m; 8700 to 8200 years B.P.) has a highly significant percentage and influx decline in spruce. Pine shows two significant percentage drops, approximately mimicked in influx, but is more stable than spruce. Alder values drop to the lowest since the early postglacial and poplar pollen has almost vanished. Birch shows a percentage and influx peak in mid-zone. The size distribution indicates a predominance of tree birch greater than that found at present. Grass and sedge percentages and influx values drop from the previous level, but the representation of most other taxa remains unchanged. Total influx rises intermittently to >13,000 grains cm^{-2} $yr.^{-1}$.

In BL6 (4.20 to 2.50 m; ca. 8200 to 5800 years B.P.), spruce, alder and birch show opposite trends to pine. The former taxa decline to a minimum at 7400 years B.P., when pine peaks. These trends also appear on the influx diagram. Most other taxa are complacent in their representation, but milfoil shows a distinct percentage and influx rise at 3.40 m, about 6900 years B.P. A notable feature of BL5 is an influx peak with high but erratic fluctuations, up to 37,599 grains cm^{-2} $yr.^{-1}$ at 3.50 m.

BL7 (2.50 to 0.00 m; 5800 years B.P. to present) shows minor changes in pollen percentages. Spruce has two low values at 1.75 and 1.25 m and shows a gradual decline above 1.00 m. Pine representation drops at 1.65 m and between 1.00 and .40 m. Alder shows an overall rise with a low at 1.30 m. Birch has the same low point, and size distributions suggest an increasing importance of shrub birch. Other taxa show little change in representation, except for a minor grass peak at the top of the core.

Spring Lake zones

The following discussion refers to the Spring Lake pollen percentage diagram (Figure 12) and influx diagram (Figure 16). SL1 (4.64 to 4.40 m; ca. 11,700 to 10,800 years B.P.) is a deciduous tree - shrub - herb zone. Spruce and pine percentage and influx values are low. Poplar is at least 40% of the sum, and has high influx values. Willows and soapberry are prominently represented, and sage and grass are prominent in the upland pollen percentage. The Chenopodiineae are consistently represented at low values with a clustering at the base, although it is not known if clustering produces the high level of significance associated with its distribution (Table 1). Amongst the aquatics or emergents, sedges and *Typha* are prominent, and *Myriophyllum* has a low but consistent representation. The high undeterminable percentage results from eroded poplar or sedges. The pollen influx rises from 500 grains to >4000 grains cm^{-2} yr^{-1}.

SL2 (4.40 to 4.15 m; ca. 10,800 to 8700 years B.P.) is a coniferous tree zone. Spruce and pine are more or less as abundant in influx and percentage as they are at present. Both show significant percentage and influx declines in mid-zone. Birch rises to an influx and percentage peak at the end of the zone. Poplar percentage and influx declines sharply at the beginning of SL2. Willow shows a marked decline in SL2. *Thalictrum* and grasses have low, consistent representations. Sedge percentages and influx are below SL1 levels. Total pollen influx rises in time from 4000 to 10,000 grains cm^{-2} yr.$^{-1}$. SL2 has the lowest sedimentation rate of the whole core, 90 yrs. cm^{-1}.

SL3 (4.15 to 2.65 m; ca. 8700 to 4800 years B.P.) shows a pine rise and peak to >70%, with an influx peak early in the zone, followed by a subsequent long-term decline. There are minor peaks in spruce, alder, birch, and willow concurrent with a pine low at 5700 years B.P. Birch has a minor low at 4.00 m, followed by an increase at 3.90 m, shown in percentage and influx. Alder has a single peak in percentage and influx at 2.50 m, and willow has several percentage and influx peaks in the latter half of SL3. Sage, Chenopodiineae, and grasses maintain consistent low levels of representation, as do the sedges, Potamogeton, Typha, and Myriophyllum. Total pollen influx averages 5000 to 7000 grains cm^{-2} yr.$^{-1}$, and rises sharply to 30,000 grains cm^{-2} yr.$^{-1}$, by the end of the zone.

In the SL4 sediment (2.98 to 1.00 m; ca. 4800 to 2400 years B.P.) lamination becomes discontinuous. Pine and spruce values show minor inverse fluctuations. Alder and birch are basically stable, with two percentage and influx lows. The representation of willow, sage, Chenopodiineae, Thalictrum, grass and sedge is either reduced or more sporadic than in the previous zone. The shrub and herb sum in SL4 is notably lower than in SL3. SL4 has high but fluctuating influx values, mostly >12,000 grains cm^{-2} yr.$^{-1}$.

In SL5 (1.00 to 0.00 m; ca. 2400 years B.P. to present) spruce shows a gradual decline and then a slight final rise both in percentage and influx. Pine has irregular but significant fluctuations. *Equisetum* has two notable percentage and influx peaks. Other taxa show neither distinct trends nor variations from SL4. Total influx gradually declines through the zone, with a sharp final increase.

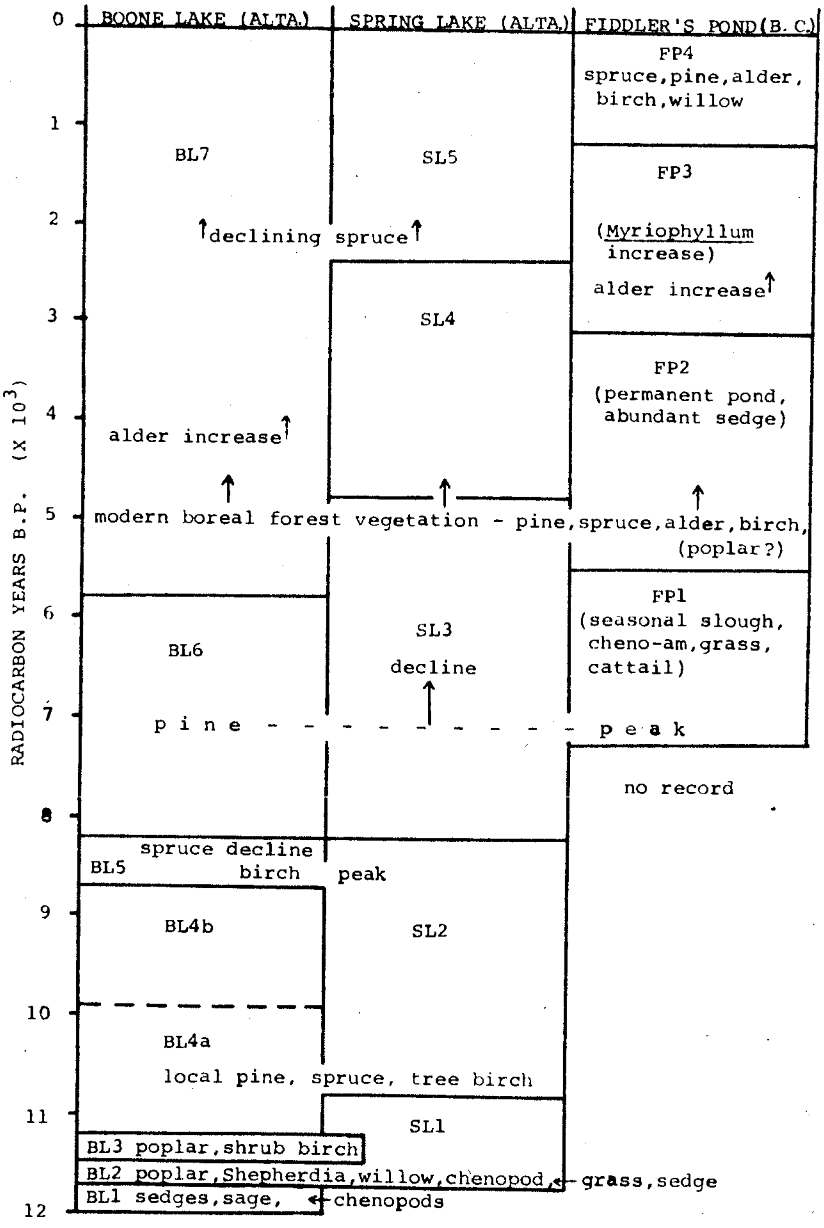
VI. Peace River District Pollen Zonation and External Correlation

The following is a synthesis of Boone Lake, Spring Lake, and the Fiddler's Pond (White and Mathewes 1982) pollen diagrams to produce an interpretation of Late Quaternary vegetational change in the Upper Peace River district of Alberta and British Columbia (Figure 17).

BLA,B is the most intensively analysed core, and has the greatest radiocarbon time control. In addition, the broad, unsheltered basin is likely to reflect regional pollen rain. It is expected that the smaller, more sheltered and steep-sided Spring Lake basin, and the much smaller Fiddler's Pond, will show more local and extralocal patterns of vegetation development. Thus, Boone Lake has been used as a master sequence. Where analagous pollen zones are shown to exist in Boone and Spring Lakes, but are not shown to be contemporaneous by the independent radiocarbon control, the Spring Lake sequence has been chronologically fitted to the Boone Lake sequence.

BL1 is summarized from Part A. It extends from about 12,000 to 11,700 years B.P., and has not been defined in Spring Lake. It was a period of active ice melting. An ice mass stood just north and west of Boone Lake, and glacial meltwater entered the lake from the northeast and exited to the southeast, draining into some stage of Glacial Lake Peace. Although near an ice margin, Boone Lake supported an aquatic and emergent flora of

Figure 17. Regional correlation diagram.


BOONE LAKE (ALTA.)
SPRING LAKE (ALTA.)
FIDDLER'S POND (B. C.)
RADIOCARBON YEARS B.P. (X 10^3)
0
1
2
3
4
5
6
7
8
9
10
11
12
FP4
spruce, pine, alder, birch, willow
BL7
SL5
FP3
declining spruce
(*Myriophyllum* increase)
alder increase
SL4
FP2
(permanent pond, abundant sedge)
alder increase
modern boreal forest vegetation - pine, spruce, alder, birch, (poplar?)
BL6
SL3
decline
FP1
(seasonal slough, cheno-am, grass, cattail)
pine - - - - - - - - - - peak
no record
spruce decline
BL5
birch peak
BL4b
SL2
BL4a
local pine, spruce, tree birch
SL1
BL3 poplar, shrub birch
BL2 poplar, Shepherdia, willow, chenopod, grass, sedge
BL1 sedges, sage, chenopods

sedges, *Polygonum amphibium*, *Myriophyllum*, *Typha*, *Potamogeton*, the algae, *Chara*, *Pediastrum*, and the moss, *Drepanocladus crassicostatus*. Gastropods, ostracods, *Daphnia* and chironomids also occupied the lake. An upland herbaceous vegetation included sage, Chenopodiineae, grasses, probably sedges, and other herbs. Birch, soapberry, and buckthorn were upland or wetland shrubs. Scarab beetles possibly occupied the littoral area. By the end of this zone balsam poplar was growing on the shores of Boone Lake. The lake level must have been lower than present at this time, possibly as a result of melting of an ice mass, permitting drainage down present Boone Creek.

In the Spring Lake basal clay there is puzzling evidence of regional pine presence. Regional pine presence is unlikely during the time of BL1 because of the low pine percentage in that zone. The pine may therefore have been regionally present sometime before BL1, but this pine presence remains undated.

BL2, BL3, and BL4a are correlated with SL1. The Boone Lake zones will be discussed separately as they present a more detailed picture of early vegetation change, and will then be compared to SL1. Boone Lake 2, from about 11,700 to 11,500 years B.P. represents a deciduous tree - shrub - herb zone. The presence of the dominant poplar is demonstrated by macrofossil and pollen evidence. Conifers were apparently not regionally present. Influx, and percentage values suggest long-distance transport (Webb and McAndrews 1976). Shrub birch, willow, soapberry, and probably rose were local shrubs. The presence of soapberry at 3% indicates an abundance of this entomophilous taxon in the vegetation. The Tubuliflorae, sedges, Chenopodiineae, and grasses were important upland herbaceous elements. It is likely that the sedges occupied both the uplands and the lake shores, given the present abundance of sedges in the Peace River grasslands. The prominence of shrubs and herbs in the pollen sum argues for the absence of a closed canopy. All aquatic or emergent elements of BL1 continued to be present, and *Ceratophyllum demersum* was also present.

The sediment deposited in BL2 was gyttja, demonstrating a productive aquatic and upland environment and minimal erosion.

Gyttja in BLD as well as BLA,B at this time indicates an increased water level, which requires a geological explanation. There is no local evidence of a blockage in drainage; indeed, Boone Creek is downcut. A partial explanation may be found in isostatic rebound. The major component of rebound is about .4 m km^{-1} westward uplift (Mathews 1980). Boone Creek and Pouce Coupe Creek drain about 46 km westward before turning north. Isostatic rebound could have reduced the gradient in this section of stream, resulting in reduced drainage and local ponding.

BL3, from about 11,500 to 11,300 years B.P. is a transitional zone between the early deglaciation period vegetation formation and the subsequent clear presence of a local coniferous forest.

There are minor influx declines in poplar, willow, and sage, and minor influx increases in pine, birch, and grass, but the percentage effects of these changes are marked. Only sedge shows a distinct percentage and influx decrease.

The distributions of *Viburnum* and probable *Corylus* pollen suggest the presence of these shrubs near Boone Lake. Entomophilous *Viburnum* is likely underrepresented, and anemophilous *Corylus* is likely overrepresented. *Corylus* is presently more abundant in the aspen parkland south of the study region (Moss 1953a) than in the Peace River area, so this data suggests a northerly extension of the zone of abundance of *Corylus*, likely as a result of a more open forest. The Rosaceae may be the aggressive *Rosa acicularis* or *R. woodsii*.

A comparison with SL1 indicates that the *Populus* decline is more apparent than real, resulting from changing preservation conditions. Although spruce is slightly underrepresented (Webb and McAndrews 1976), it reaches 10% in this zone. However, the lack of a major influx rise suggest that it is not regionally present, except as a very minor element. Likewise, the highly over-represented pine (Webb and McAndrews 1976, Lichti-Federovich and Ritchie 1968), is unlikely to be regionally present except as a minor element in spite of a rise to >20% and a clear but minor influx rise.

Alder can be highly over-represented in a forest, forest - tundra, or tundra zone (Lichti-Federovich and Ritchie 1968, Ritchie 1974, Schweger 1976). Therefore, the tree is probably more sparse than its percentage would suggest. On the other hand, the vegetation percentage of willow may more or less approximate its pollen percentage, although this is not invariably true (Ritchie 1974). Tree birches were increasing in local importance during BL3, although the percentage increase may represent change from an under-represented shrub birch to an overrepresented tree birch (Schweger 1976).

In sum, the regional vegetation was likely similar to BL2, an open poplar and deciduous shrub woodland with an important heliophilic herb cover. Tree birches might have arrived during this time, and conifers were likely approaching.

The increase in grass and decline in sedge both in influx and percentage suggests some replacement of sedges with grass on the uplands.

Total pollen influx is consistent with modern tundra of forest-tundra influx (Ritchie and Lichti-Federovich 1967, Schweger 1976). Although the pollen influx may be consistent with these formations, they present a better physiognomic than floristic analogue for this zone. Particularly, the Chenopodiineae characterize grasslands, rather than tundra (Mott 1969, Mott and Jackson 1982). Corylus ty., if it represents the taxon Corylus, is reconcilable with grassland to boreal environments, but not with tundra. A deciduous tree - shrub - herb vegetation with more southern grassland - parkland floristic affinities is indicated.

BL4a shows the first strong evidence of regional spruce and pine. Spruce reaches a value of 12% at the beginning of the zone and 22% by mid-zone at 4.98 m. Pine is 24% at the beginning of the zone and rises to 45% by mid-zone. Mid-zone spruce influx is 600 grains cm^{-2} $yr.^{-1}$, and pine is 1400 grains cm^{-2} $yr.^{-1}$. The middle of the zone is dated at 10,740 ± 395 years B.P. (WAT 362). In Spring Lake a spruce rise to 19% and pine rise to 45% occurs at the base of SL2 at 4.40 m. Influx is 900 grains cm^{-2} $yr.^{-1}$ for spruce and 2200 grains cm^{-2} yr^{-1} for pine. At Spring Lake the conifer rise is directly dated at 10,800 ±180 years B.P. (SFU 210). A conservative date for the conifer rise would be 10,400 years B.P., obtained by subtracting 1 standard deviation from WAT 362 and 2 standard deviations from SFU 210.

At Lofty Lake, a spruce forest without the prominent herbaceous elements of the early postglacial prairie spruce zone (Ritchie 1976) defines the assemblage of L2 (Lichti-Federovich 1970). By interpolating between the two lowest ^{14}C dates, one can estimate the spruce rise to be at 10,800 years B.P., more or less contemporaneous with the Saddle Hills spruce rise.

Hopkins _et al._ (1981) have suggested that spruce did not survive in Beringia during the Late Wisconsinan. Rather, it migrated behind the retreating ice from the early postglacial midwestern spruce forests to first appear in northeastern Beringia near Inuvik and Tuktoyaktuk at 11,500 years B.P. Although Hopkins _et al._ concluded otherwise, it seems improbable that spruce could have migrated from the prairies to the Mackenzie Delta area by 11,500 years B.P. without previously being established in the Lofty Lake and Saddle Hills regions, if Prest's (1969) speculative ice margins for 11,500 to 12,000 years B.P. are valid.

It is conceivable, however, that if seeds of spruce from stands on stagnant ice, or from possible refugial areas such as the Clear Hills were dropped into glacial meltwater draining towards the Arctic Ocean, spruce could have been dispersed within a season or two to the Mackenzie Delta area, without showing a time transgressive distribution in the intervening region. In the deltaic habitat spruce could have rapidly established local stands. The distribution of southern spruce propagules by water to the Mackenzie Delta could apparently have taken place during or after the Indian Creek stage of Glacial Lake Peace, when meltwater from the upper and middle Peace River region could have flowed into the Nelson River (Mathews 1980). The Indian Creek stage has been indirectly dated in this study as occuring some time prior to 10,400 years B.P., while Prest (1969) has dated the ice margin causing this proglacial lake stage at 11,200 years B.P. This is substantially closer to the time of arrival of spruce in Beringia. Unfortunately it is still earlier than an admittedly conservative interpretation of regional spruce in the Upper Peace River area, which would likely have served as a source of spruce seeds.

The contemporaneous rise of pine with spruce in BL4a explains the lack of a spruce dominated assemblage, such as L2 (Lichti-Federovich 1970), or the early postglacial prairie assemblage (Ritchie 1976).

The sources of *Pinus contorta* ssp. *latifolia* and *Pinus banksiana* are important questions for western palaeoecology. Wheeler and Guries (1982) have suggested a Yukon refugial source for *P. contorta* ssp. *latifolia* of the modern Yukon and northern British Columbia. They proposed that two southern refugial centres were the sources of lodgepole pine (ssp. *latifolia*) of the southern intramontane areas of British Columbia and western Alberta. A pine migration would probably have taken place along the Ice-free Corridor of southwestern Alberta. Chalmers Bog zone CB2 (Mott and Jackson 1982) shows rising pine values, but the wide latitude of its chronology does not help in tracing a pine migration. However, the authors report high pine values from a buried organic layer in the Elk Valley dated at 11,900±100 (GSC 2142) and 12,200± 160 (GSC 2275) years B.P., suggesting a northward migration of pine along the mountain front. Pine shows high influx and percentage at Wabamun Lake by 10,400 years B.P. (Holloway *et al.* 1981), but acceptance of this date should await a firm identification of the tephra immediately above it.

The pine rise in the Saddle Hills is assumed to represent *Pinus contorta* ssp. *latifolia*, on the basis of its modern distribution. The Saddle Hills pine rise is substantially earlier than the pine rise at Lofty Lake in L4, about 7500 years B.P. (Lichti-Federovich 1970). It is a puzzle why pine did not migrate eastward to Lofty Lake during this time period. However, the slight rise in pine percentage in L2 might suggest an eastward incursion of lodgepole pine between 10,800 and 9200 years B.P. If this happened, it would have been replaced by later migrating jack pine. Ritchie (1976) concludes that jack pine migrated to the boreal forest of northern Saskatchewan and Manitoba from the west, but the refugial source for this taxon remains an enigma.

The sharp rise of the conifers and tree birch in mid-BL4a might be explained by two alternative hypotheses: 1) that the two conifers and tree birch arrived in the Saddle Hills area contemporaneously, or 2) that these taxa existed in the area in limited numbers previously, and a climatic amelicration resulted in the contemporaneous local expansion of these elements. The data from the present study are not sufficient to resolve which alternative is preferable.

The SL1 pollen zone is equivalent to BL2, BL3, and the early part of BL4a. It has the same low conifer, birch, high poplar, high willow, soapberry, sage, grass, and sedge values. Chenopodiineae are less well represented in Spring Lake suggesting local site factors influence its presence. Radiocarbon dates place the beginning of SL1 at 11,200±400 years B.P. (WSU 2557), which is about 500 years after the end of BL2. The pollen stratigraphy argues strongly for contemporaneity, so SL1 has been adjusted to 11,700 years B.P., which is within +1.25 s of the mean date. It was decided to make SL1 older rather than BL2 younger because of the wide standard error of WSU 2557. Furthermore, the equivalent zone at Lofty Lake (Lichti-Federovich 1970) begins at 11,400 years B.P. The Saddle

Hills would have been exposed earlier in deglaciation than the Lofty Lake area (Prest 1969), arguing that the BL2-SL1 zone is earlier than L1 at Lofty Lake.

A minor but significant percentage decline takes place in birch in SL1 at 4.40 m. This is apparently correlated with the first major birch decline in Boone Lake at 4.90 m. A significant pine peak just before the birch decline in each core strengthens this interpretation.

The mid-BL4a conifer rise and the SL1-SL2 transition conifer rise correlate well by direct ^{14}C dating (see above).

Poplar percentage and influx in BL2-4a are lower than in SL1. This is likely a joint artifact of the greater percentage of birch in BL4a, and of a superior preservation of poplar in the meromictic Spring Lake, than in holomictic Boone Lake. The poplar percentage in the latter half of SL1 depresses the conifer percentage so that they appear lower than in the contemporaneous BL3. There are in fact no marked differences in conifer influx at this time.

During BL2 and 3 and SL1 it is possible that Glacial Lake Peace was receding to its lowest stage, and periglacial mound formation was taking place.

The BL2 to 4a and SL1 pollen zone, with very low spruce and a high poplar percentage, is distinctly different from the assemblage which dominated southern Saskatchewan and Manitoba between deglaciation and 10,500 years B.P. (Ritchie 1976). However, these zones are similar in the importance of willow, sage, grasses, and sedges. The Saddle Hills zones fit well with L1 at Lofty Lake (Lichti-Federovich 1970) but the Boone Lake sequence shows a more detailed transition from the early vegetation to the coniferous forest than Lofty Lake. The lowest zone of Flin Flon shows similarities to L1 (Ritchie and Yarranton 1978). All sites which show this early zone lie north of 54°45', while sites dominated by spruce lie further south.

No modern analogue has been found for the early Saddle Hills - Lofty Lake deciduous woodland - shrub - herb assemblage.

Late-BL4a,BL4b and BL5 correlate with SL2. The SL2 record is apparently compressed. The interpolated ^{14}C date in Spring Lake makes SL2 coincide exactly with the end of BL4b at 8700 years B.P. However, the pollen stratigraphy argues that the proper alignment is with BL5.

A sharp birch decline, apparently of tree birch, characterizes the ends of BL5 and SL2. The pattern of declining and then rising pine in SL2 fits the pine pattern apparent between BL4a and BL5. The spruce percentage patterns in BL4a and BL5 and in SL2 are different. The periods of significant fluctuation in Boone Lake apppear as a slight decline and rise in Spring Lake. The Spring Lake sampling interval might fortuitously have masked this variation. Otherwise, it is not clear why significant declining trends would appear in Boone Lake but not in Spring Lake.

The low shrub and herb values at BL5 correlate with equivalently low values in the upper half of SL2. However, these low percentages appear to be effects of increased pine and birch sums. There are no equivalent trends in influx.

A notable feature of BL4b is the initial birch drop, apparently in tree birches, and a subsequent rise to a peak and decline in BL5. As noted above, the pattern is clear although more subdued in SL1 and SL2. The Boone Lake birch size distributions suggest that the first decline in birch was in the proportion of upland tree birches, and that tree birch became more abundant over the subsequent 2000 years. The reason for the fluctuation is unclear. Birch was a much more important upland element at this time than it is at present. Birch apparently was in competition with poplar, which it partially replaced as an upland element. Interpretation of the ecology of this event is complicated by the uncertainty over which *Populus* and which *Betula* species are involved in this transition. Assuming that *P. balsamifera* and *P. tremuloides*, *B. papyrifera* and *B. occidentalis* are involved, it is possible that the slightly greater shade tolerance of birch was an important factor (Fowells 1965, Krajina *et al.* 1982).

The pollen percentage fluctuations in BL4a, BL4b and BL5 make it difficult to characterize these zones or define modern analogues. SL2 presents more stable spectra, and it may be roughly characterized as spruce 22%, pine 35%, alder 3%, birch 20-30%, willow 5%, and grass <1%. The eastern subzone of the open coniferous forest (Lichti-Federovich and Ritchie 1968) appears to present approximate analogues, although the SL2 spectrum contains less spruce and alder and more birch and willow. Nonetheless, the fluctuations of the BL4a to BL5 spectra at the same time serve to emphasize that an open coniferous forest is merely a rough analogue within which much vegetation fluctuation took place.

Birch was an important element in L3 at Lofty Lake (Lichti-Federovich 1970) between 9180 and 7400 years B.P., equivalent in time to the Saddle Hills birch dominance. At Lofty Lake, however, birch replaced poplar after the interlude of spruce dominance. Apparently birch also had some competitive advantage over spruce in the prevailing environment. Likewise in BL5, the rise of birch is marked by a decline in spruce influx and percentage, while pine was little affected. On the other hand, in SL2 the birch rise depressed pine percentages, with spruce being less affected. This is not as distinctly marked in influx, however. The reason for this is unclear, but probably lies in site factors. Some climatic factor may likewise have given birch a competitive advantage over the conifers.

The possibility that the clay band at the base of BL4b represents some significant geological or climatic event has been advanced by White <u>et al.</u> (1979). The clay band has been shown by the BLD core to be not continuous in the Boone Lake sediment. The reworked palynomorph spectrum of the clay band compares well with the spectra in the Boone Lake basal clay (Figure 6), indicating that the source of the clay was the local proglacial deposit. A clay band was not found in Spring Lake, which is at a lower elevation than Boone Lake . Thus, the hypothesis that the clay band represents a late rise of Glacial Lake Peace is rejected.

The climatic hypothesis can not be so easily rejected. Some erosional event caused a discontinuous clay band to be deposited in Boone Lake. Contemporaneously, the abundance of tree birch, and influx of pine, spruce, alder, shrubs and herbs dropped sharply in influx and percentage. Spruce subsequently showed sharp percentage fluctuation, and willow, grass, and sedge became more important in percentage and influx. The deposition rate was very slow, or the sediment deposition was interrupted. At the same time Spring Lake experienced a pine percentage and influx decline, an influx decline in spruce, shrubs, and herbs, and a slow deposition rate. Thus, the pollen evidence suggests some event of greater magnitude than local erosion at Boone Lake. A cooler period would seem to be indicated. A climatic alteration might explain the Lofty Lake L3 birch rise (Lichti-Federovich 1970). The undated Redwillow Valley advance and the late Halfway River advance might also correlate with this time (see Mathews 1978,1980).

BL6 and SL3 are largely contemporaneous, from 8200 to 5800 years B.P., although SL3 continues to 4800 years B.P. In the absence of clear pollen-stratigraphic markers after the pine peak, the radiocarbon chronology for each core is accepted to control zone boundaries.

The salient feature of these zones is the pine peak with percentage values of about 70%, following the birch decline. The pine peak is dated at 7400 years B.P. by SFU 206 in BL4b. As pine is an overrepresented, regionally distributed pollen type (see discussion in White and Mathewes 1982), it seems appropriate to consider the pine peaks to be contemporaneous. In BL6 the pine percentage peak is supported by a strong pine influx peak, but no notable influx rise takes place in SL3.

The pine peak correlates with the Hypsithermal in western Canada (see White and Mathewes 1982). Hypsithermal is considered here to be a time-transgressive climatic event (Wright 1976) rather than a time-stratigraphic event as defined by Deevey and Flint (1957). Presumably pine's adaptation to fire and an ability to survive on dry habitat resulted in its prominence during this time.

The Hypsithermal effect on the Peace River grasslands is an important question. If there was ever a major expansion of the regional grasslands, it would probably have been at this time. Nonetheless, the grasses, sage, and sedges show no prominent alteration in influx or percentage with the pine peak. On the other hand, the grasslands surrounding the Saddle Hills before the agricultural settlement period are not clearly represented in the upper levels of either core, so one may question whether more extensive grassland would be represented in pollen diagrams, especially as the dominant <u>Carex</u> -<u>Danthonia</u> - <u>Stipa</u> community is only 45% grass.

Lichti-Federovich and Ritchie (1968) have shown that the grass pollen percentage in aspen parkland is between 10% and 20%. McLennan (1981) demonstrated that grass pollen can be transported at least 8 km upslope from the source to the depositional site. Webb and McAndrews (1976) determined that the grass pollen rain from aspen parkland and grassland is transported into the southern boreal forest, giving grass values there of about 5%. In the latter case, however, the pollen source is much more extensive than the Peace River grasslands. Nonetheless, it would appear that if more extensive grasslands were present in the Peace River area during the Hypsithermal, they should be reflected in the Boone Lake and Spring Lake pollen records.

BL6 and SL3 show no clear increase in the pollen of grass, sage or Chenopodiineae, or the high herb sums which characterize grasslands (Mott 1969). This indicates that there was no significant increase in the area of grassland, or an advance of the grassland - forest ecotone towards, or past Boone or Spring Lakes. It is therefore concluded that the Hypsithermal had little effect on the formation or extent of the Peace River grasslands.

It is also possible to reject North's (1976) suggestion that the draining of the proglacial lakes during the Hypsithermal might have contributed to the grassland origin. The evidence presented above shows that local proglacial ponds drained well before the Hypsithermal interval. Edaphic factors would thus appear to be the prime determinants of the development and distribution of the Peace River grasslands. The grasslands probably developed as Raup (1934) proposed, in situ, from the early tundra flora.

The decline in pine after 7400 years B.P. is likely a result of a stepping down from the Hypsithermal - an increase in available moisture and a decrease in fire. The initial organic sedimentation from Fiddler's Pond is at 7250±120 years B.P., and this has been interpreted as a result of greater moisture after the Hypsithermal peak (White and Mathewes 1982).

Lofty Lake (Lichti-Federovich 1970), only 450 km eastsoutheast of the Saddle Hills does not show a contemporaneous Hypsithermal event. The beginning of the grass rise, the possible local arrival of pine, and a birch decline are found at 7480 years B.P. in L4. Lichti-Federovich (1970) extended her Megathermal Period to about 3500 years B.P., but a major grass decline took place at 5200 years B.P. The Hypsithermal peak apparently took place between 7480 and 5200 years B.P.

These new data from the Saddle Hills support the conclusion previously published (White and Mathewes 1982) that the chronology for the Hypsithermal at Lofty Lake does not agree with that for the upper Peace River area. The upper Peace River chronology does correlate well with Schweger and Hickman's (1980) suggestion that the warm/arid peak occurred in central and eastern Alberta between 8700 and 6300 years B.P.

A sediment discontinuity in the Wabamun Lake pollen record between 9000 and 5280 years B.P. has been attributed to the Hypsithermal (Holloway _et al._ 1981), but the 4000 year gap in the record does not help to clarify the chronology of the Hypsithermal in central and northern Alberta.

The closest modern analogue for the pollen spectrum of the Saddle Hills at the pine peak, with pine values of about 70%, is subzone 'a' of the closed coniferous forest (Lichti-Federovich and Ritchie 1968). In this forest, spruce covers about 46% of the land, pine about 22%, and poplar about 21%. However, these modern pollen samples were collected in an area of bedrock-controlled topography with black spruce and jack pine as dominant elements. The Saddle Hills are till mantled, and likely white spruce and lodgepole pine were the major elements. Nonetheless, the analogue demonstrates that pine was probably close to 20% of the forest cover.

BL7, from 5700 years B.P. to the present, shows few distinct patterns of vegetation change, except for a consistent alder increase, a minor spruce decline, and a birch size decrease in the last 3400 years. However, the records from Spring Lake and Fiddler's Pond provide a more sensitive, but basically consistent record of vegetation change.

The beginning of BL7 is shown by direct ^{14}C control to coincide with a pine minimum in SL3, at 5700 years B.P. It is the end of a 1700 year period of a consistent pine decline in both cores, yet the Boone Lake percentages are approximately 20%

higher than the Spring Lake percentages. Local pine stands at Spring Lake must have disappeared, and the lake received only regional pine pollen rain. Less broadly distributed pollen types, spuce, alder and willow were more important in Spring Lake at the pine minimum. The intra-lake differences probably reflect a greater importance of local and extralocal pollen (sensu Janssen 1973) in the somewhat enclosed Spring Lake versus the open and exposed Boone Lake.

In late SL3 to mid SL4 pine rises to a peak about 10% higher than the very stable Boone Lake percentages, suggesting more local stands in the Spring Lake vicinity. This apparently has little regional environmental significance as no equivalent change appears in Boone Lake.

The sharp transition in influx at the base of SL4 is apparently a function of pollen concentration in the sediment, as there is no change in the calculated sedimentation rate at that point. This influx increase begins at the same level as the zone transition calculated from the percentage diagram, emphasizing the significance of the change. Pine and spruce have the most distinct changes. Perhaps with more humid conditions the steep western slope of the Spring Lake basin was recolonized by high pollen producing conifers, resulting in a sharp influx rise and a more subdued percentage change.

In the upper metre of BL7, after 3400 years B.P., spruce began a slow decline, apparently losing some importance to alder. Alder is an understory, rather than a canopy species on the uplands. Pine and other taxa remained unchanged. A steady decline in the mean size of birch grains indicates an increasing proportion of shrubby birches. Dwarf birches were probably colonizing the peatland to the west and south of Boone Lake, and increasing their contribution to the local pollen rain. To give an unchanged birch percentage within the pollen sum, the upland birches must have been declining in abundance to some degree. The change may best be interpreted as accelerated hydroseral succession under slightly moister and perhaps cooler conditions.

The pattern of spruce decline has been noted in the Boone Lake, Spring Lake and Fiddler's Pond cores in the last 3000 years, and of alder increase in the Boone Lake and Fiddler's Pond cores over the same time period. Both taxa would be favoured by increasing moisture, so this change is inexplicable just by cooler, moister climatic conditions.

A small but distinct rise in grass pollen in the surface sample from Boone Lake likely reflects historic clearance of now abandoned farmland just southwest of Boone Lake. The absence of a small surface grass peak in Spring Lake confirms that it was local agricultural clearance near Boone Lake, rather than the agricultural occupation of the Peace River grasslands which is responsible for the Boone Lake grass rise.

FP3 and FP4 (White and Mathewes 1982) show essentially modern conditions for the last 3100 years, agreeing with the Saddle Hills data. Lofty Lake (Lichti-Federovich 1970) underwent little change in the last 3800 years, and this is in accord with established patterns in the Pacific Northwest and northwestern interior (see White and Mathewes 1982 for discussion).

SUMMARY

The following summarizes the principal conclusions from this research.

1. Ice overrode the Saddle Hills during the Late Wisconsinan advance, and local ice-blockage of the 'Ice-free Corridor' is indicated at least during the latter part of the Late Wisconsinan.
2. The earliest palaeoecological record is from Boone Lake Zone 1, between approximately 11,700 and 12,200 years B.P. Boone Lake was an enlarged pondage, dammed by an ice mass to the west, and receiving meltwater from an ice mass to the north. During this time a sparse tundra-like vegetation consisting of herbs and scattered shrubs existed around Boone Lake. The most important taxa were sedge, sage, grass, and chenopods. Algae, moss, and beetles existed in and nearby Boone Lake.
3. Boone Lake Zone 2 vegetation was probably parkland with continuous vegetation cover of poplar trees, soapberry, willow, sage, grass, and upland sedge. There is a probability of 0.65 that this vegetation existed in an habitable, ice-free area in the Saddle Hills prior to 11,600 years B.P.
4. Pine and spruce were present in the upper Peace River region probably by 10,700 years B.P., and certainly by 10,400 years B.P. Forest at that time approximated modern boreal forest, with more clearings. Spruce could probably not have migrated from the Peace River area towards Beringia prior to that

time.

5. Birch became a more important element than it is in the modern boreal forest between 8700 and 8200 years B.P.
6. The Hypsithermal peak in the upper Peace River region occurred at 7400 years B.P., indicated by a peak in pine percentages. The historic Peace River grasslands can best be explained as an edaphic climax vegetation, and not as relics of a Hypsithermal northern extension of the main grasslands.
7. Wetness increased after 7400 years B.P., resulting in a pine decline. Permanent ponds developed out of former seasonal sloughs by 5700 years B.P.
8. Essentially modern boreal forest conditions have prevailed since 5700 years B.P.

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