A PALAEOECOLOGICAL INVESTIGATION AT TREELINE, YELLOWKNIFE, NWT

A PALAEOECOLOGICAL INVESTIGATION OF THE TREELINE ZONE NORTH OF YELLOWKNIFE, NWT

by

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ABSTRACT

The pollen, charcoal and sediment stratigraphies of two cores from small lakes located northeast of Yellowknife, NWT are examined. The focus of this study is to reconstruct post-glacial vegetation changes in this climatically sensitive area. The resulting vegetation history is compared to similar reconstructions from across Canada. The pollen content of twenty-eight modern sediment samples, collected from the forest, the forest-tundra and the tundra zones were used to aid in the interpretation of the fossil record. Radiocarbon dates indicate that the fossil records from these lakes span ~7 500 years. The initial vegetation, shrub *Betula* tundra, was established at ~7 000 BP and persisted until ~6 000 BP. The presence of Ericaceae, *Myrica*, and *Sphagnum* distinguishes this zone from similar zones from western Canada and suggests the existance of large areas of bog environment. This zone is succeeded by a second shrub tundra zone, which is marked by a dramatic increase in *Alnus crispa* and *Alnus incana*. This zone spans from ~6 000 BP until ~5 000 BP. A synchronous increase in *Alnus* is noted from sites across Canada and is attributed to an increase in moisture. The third zone, spanning from ~5 000 BP to ~3 500 BP, delimits the existance of forest vegetation defined by the northward expansion of *Picea*

mariana. The delay of *Picea mariana* expansion into the area relative to its arrival in western Canada can be explained by one of the following:

1) geological differences; or
2) remnant glacial ice retarding climatic amelioration; or
3) the long-wave westerly disturbance, which causes cooler temperatures in the east when warmer temperatures persist in western Canada; or
4) some combination of the above.

The decline of forest vegetation at ~3 500 BP marks the establishment of modern tundra vegetation at both sites. Climatic cooling coupled with fire caused the extinction of aboreal vegetation at the study sites.

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CHAPTER 1 INTRODUCTION

The northern treeline is one of the most continuous and intriguing geographical boundaries in Canada. It stretches over 4 000 km; from the far northwest corner of the Yukon, southeast across the Northwest Territories to the western shore of Hudson Bay, and then northeast across Quebec to Ungava Bay and Labrador. The boundary marks the northern limit of arboreal vegetation. Beyond it, flora is reduced to a cover of shrubs, herbs, grasses, sedges and non-vascular plants. Although the boundary is not always as obvious as depicted on maps, this relatively sharp ecotone has provoked extensive study by botanists, climatologists, pedologists, and palynologists. One of the fundamental aims of these groups is determining the critical environmental factors limiting the northern extent of trees. Climate has been considered as the paramount parameter (Hare, 1951). Studies have demonstrated a direct relationship between dominant air masses and vegetation (Bryson, 1966). This link has led palynologists to analyze fossil pollen to determine past vegetation types from which to infer past climatic conditions.

The following section provides an overview of research on the modern and palaeoecological aspects of the northern treeline that form the basis from which this thesis has evolved. Treeline terminology will be explained and research concerning the relationship between climate and vegetation will be discussed. Finally, the use of modern climate/vegetation relationships to establish past climates from fossil (especially pollen) evidence will be reviewed.

1.1 Treeline

Surprisingly, opinion varies on the precise definition of 'treeline'. Treeline has been referred to as the boundary between the boreal forest and forest-tundra (Elliott, 1983); the forest border (Sorenson et al., 1971); the transition between forest and tundra vegetation (Larsen, 1980); the northern edge of the forest tundra (Ritchie and Hare, 1971); and the northern limit of trees (Payette, 1983). To further complicate the matter terms such as treeline, forest-limit, limit of continuous forest, forest line, and timberline have been used interchangeably.

It may seem trivial to be concerned with the definition of treeline but it becomes important in palynological studies which attempt to determine whether or not, and by how much, treeline has moved in the past. If one study concludes that 'treeline' (meaning the boundary between the forest and forest-tundra) existed 300 km north of its present position, while another study concludes that 'treeline' (meaning the boundary between the forest-tundra and the tundra) has only advanced 100 km north of its modern location, the reader will assume that unequal treeline displacement occured in the two areas. In fact, because of the different definitions used, treeline advancement may have been congruous.

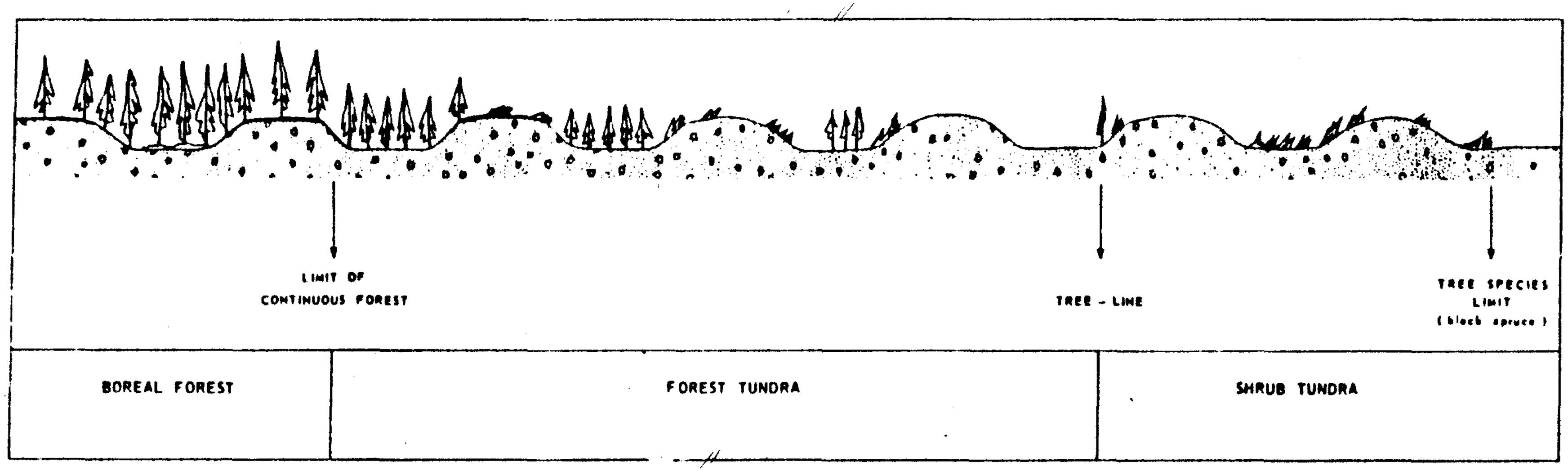
It would be useful if a single treeline definition could be agreed upon by the scientific community. However, ambiguity has prevailed from 1966 when Hustich first discussed this problem. Perhaps the best that can be hoped for is that well-defined terms are designated and consistently used in each paper.

The terminology which will be used in this study was presented by Payette (1983). It was developed from the work of Hustich (1966) and is consistent with the nomenclature used by Hare (1950), Hare and Ritchie (1972), Rowe (1972) and Black and Bliss (1978).

According to Payette (1983) three distinct vegetation zones can be identified in the transition from forest to tundra vegetation. The most southerly is the forest zone, which is characterized by a closed or continuous canopy. Moving northward the forest is confined to areas with particularly favourable conditions, often along the shores of lakes and rivers. The result is patches of forest interspersed with natural tundra openings. Further north, the forest all but disappears, leaving the open expanse of the tundra. The only remnant of the forest are lone individuals or small clusters of prostrate Picea (spruce) shrubs.

A number of terms exist to describe the boundaries marking changes in the arboreal vegetation across these three zones. Figure 1, from Payette (1983), provides a cartoon summary of these descriptive phrases. The limit of continuous forest marks the boundary between boreal forest

Figure 1: **Treeline terminology.** The continuous forest limit, treeline, and tree species limit is illustrated (from Payette, 1983).


LIMIT OF CONTINUOUS FOREST
TREE – LINE
TREE SPECIES LIMIT (black spruce)
BOREAL FOREST
FOREST TUNDRA
SHRUB TUNDRA

and forest-tundra. It refers to the limit of a continuous canopy. **Treeline is coincident with the boundary between the forest-tundra and tundra**. Payette (1983) defines it as the northern extent of "tree individuals characterized by a tree growth-form and a height of 5m or more" (pp.6). It is not synonymous with species limit, which refers to the northernmost extent of given species regardless of growth form (Payette, 1983; Spear, 1983). Having defined treeline, the factors controlling this boundary can be considered.

1.3 The Relationship Between Climate and Treeline

Ecologists have been interested in determining the precise environmental factors that limit tree growth at the northern treeline. The environmental variable which has been most thoroughly examined is climate. In 1928, Stupart wrote that "in the northern portion of the northwestern territory there are vast tracts of land where the climate is so completely dominated by arctic influences that the country is treeless and agriculture is impossible" (pp. 41). Halliday and Brown (1943) noticed the relationship of the northern and southern limits of a number of tree species with July isotherms. Later, thermal efficency, defined from potential evapotranspiration was correlated with each of the three tree vegetation zones (Hare, 1950).

Detailed studies of the vegetation around Ennadai Lake, NWT revealed that over a distance of only 80km the forest 'disappeared'. Larsen (1965) noted that it was difficult to beleive that climatic conditions could vary sufficently within such a short distance to explain such gross changes in vegetation. However, the uniformity of topography and edaphic conditions led him to conclude that, in fact, climate must be the controlling factor.

By 1966, research indicated that the northern limit of trees was related to large scale air mass behaviour (Bryson, 1966). Air masses are 'packages' of climatic conditions determined, in this case, by the geographical origin of the air mass. The area between two air masses is referred to as a 'front' and is characterized by steep climatic gradients. In his classic paper, 'Air masses, streamlines, and the boreal forest', Bryson (1966) provided evidence that treeline was coincident with the mean July position of the arctic front; the boundary between the cold, dry, arctic air mass and the warm, moist, pacific air mass. Using a procedure different from that employed by Bryson (1966), Barry (1967) also determined the mean July position of the arctic front. His results were in agreement with Bryson's except in eastern Canada (especially over Labrador) where he located the front considerably north of the earlier construction. This discrepancy is likely a reflection of differences between the models used by each of the two authors. It is not certain which model simulates the front best (Barry, 1967), however both models show a correlation between the mean July position of the arctic front and treeline in western Canada.

The association of the long-wave disturbances of the circumpolar westerlies was subsequently incorporated into the theory of air mass/treeline relationships (Ritchie and Hare, 1971; Hare, 1973; and Barry and Hare, 1974). Present-day winter climate in North America is greatly influenced by a deep trough of low pressure over eastern Canada (~80 W meridian) and a high ridge of pressure over western Canada. A less notable wave exists in July (Barry and Hare, 1974).

If heating occurs over the Pacific the entire wave is amplified, resulting in a displacement of the arctic front and warmer temperatures in the west and cooler temperatures in the east (Namais, 1970). Thus, there is a close relationship between thermal radiation and the long wave westerlies, which in turn must effect the treeline vegetation boundaries (Hare, 1973)

Although the theory, relating large scale climate conditions to treeline, encompasses a number of climatic factors it does not incorporate vegetation/climate feed-back mechanisms (Bryson and Wendland, 1967; Larsen, 1971; 1973). Hare and Ritchie (1972) found that values of energy efficency (the ratio of net productivity to radiation) decreased from the forest to the tundra. Thus, it seems that structure of northern vegetation ecotones is in response to climatic conditions induced by the position of the arctic front, and then modified by the surface structure of the vegetation itself (Hare and Ritchie, 1972).

The preceding discussion illustrates the complexity of the climate/vegetation association in northern Canada. Climate, the controlling agent of treeline vegetation, must be viewed as a collection of interacting parameters. The inhibition or absence of tree growth in areas north of the mean July position of the arctic front, typified by cold and dry climates, demonstrate this general relationship. Climatic conditions may in turn be modified by the structure of the vegetation itself.

1.4 Past Climates Deduced from Fossil Evidence

By determining the modern climate/vegetation relationship, it becomes possible to infer past climates by reconstructing past vegetation from fossil evidence. The close link between the position of the arctic front and treeline indicates the importance of establishing past treelines in order to infer past circulation and climate at a continental scale. Fossil evidence from numerous sites near the northern treeline has been examined in an attempt to determine previous treeline positions, and deduce the affiliated changes in the frontal location.

One of the earliest studies in northern Canada focussed on the discovery of buried *Ceratophyllum demersum*, a plant species thats modern distribution is restricted to more southerly regions, near the Thelon River east of Great Slave Lake, NWT (Terasme and Craig, 1958). This discovery along with fossil pollen evidence from the same site led to the conclusion that a warmer climate must have existed in the past. The conclusions of this study are questionable, as the palynological evidence is based on a single count of 134 grains, but the study initiated further work in this region. One of these studies used fossil podzols and radiocarbon dated charcoal to estimate that at ~3 500 BP (radiocarbon years before 1950 AD) the forest limit had existed 280km north of its modern position (Bryson et al., 1965). This implied that warmer conditions had existed in the present-day tundra zone.

Following the evidence presented by Bryson (1966), that the position of treeline is coincident to the position of the arctic front, Bryson and Wendland (1967) used existing collections of fossil fauna and flora from North America to reconstruct past changes in the location of the arctic front. They concluded that the arctic front had existed much further south (as far south as the Great Lakes) during the Late glacial time, and that it occurred approximately two degrees north of its present day position between 5 000 BP and 3 500 BP. Although, as they themselves point out, there is insufficient information to fully support their hypotheses, the study provided the basis for the numerous palynological investigations of treeline sites which ensued.

Palynological studies use fossil pollen to reconstruct past environments (especially with respect to climate). A common approach to such studies is to use modern climate/vegetation relationships to infer past climatic conditions from reconstructed vegetation. This approach requires determining whether modern vegetation zones are distinguishable by their modern pollen rain, and if modern pollen spectra can be found that provide analogues for the fossil pollen spectra under study (Birks and Birks, 1980). A second approach eliminates reconstructing the past vegetation by using modern pollen/climate associations to construct mathematical transfer functions and directly estimate past climate from pollen spectra. (Birks and Birks, 1980).

The following section is a synopsis of the palynological studies from western, central and eastern Canadian treeline.

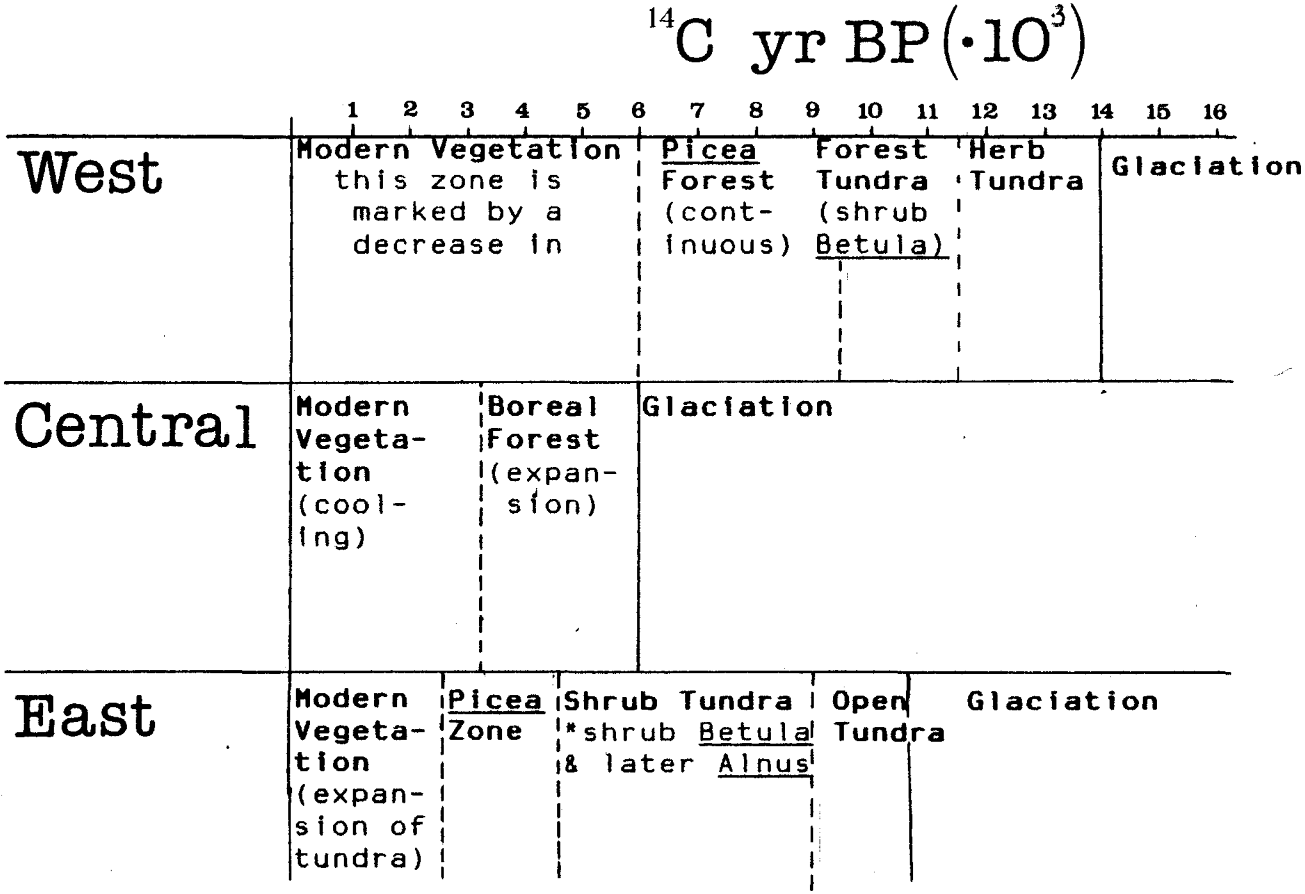
1.5 Palynological Studies at Treeline Sites

Figure 2 provides a simplified comparison of the general changes in vegetation which have been determined from pollen records constructed from data collected at treeline sites in western, central and eastern Canada. The diagram representing western Canada was reconstructed from research by Ritchie (1976; 1977; 1984; 1985), Ritchie and Hare (1971), MacDonald (1983; 1987a), MacDonald and Ritchie (1986) and Spear (1983). 'Western' Canada includes Tuktoyaktuk Peninsula and the Mackenzie River Basin. Studies by Nichols (1967a; 1967b; 1970; 1975) and Kay (1979) provide the basis for the central Canadian chronology which comprises eastern District of Mackenzie and the District of Keewatin. Pollen diagrams by Short and Nichols (1977), Lamb (1980; 1984; 1985), Richard et al. (1982) and Engstrom and Hansen (1985) were used in the generalized reconstruction for eastern Canada consisting of the Labrador-Ungava region. It should be noted that a number of minor fluctuations following ~3 500 BP (Nichols, 1967a; 1967b; 1970; 1975) have been omitted in order to simplify the diagram.

Western Canada

In western Canada, palaeoecological studies have been dominated by vegetation reconstructions from fossil pollen. Ritchie (1976; 1977; 1984; 1985) and colleagues (Ritchie and Hare, 1971; Cwynar, 1982; MacDonald, 1983; 1987a; MacDonald

Figure 2: **The post-glacial history of vegetation for western, central and eastern Canada.** This diagram generalizes the vegetational history of western, central and eastern Canada as described from analysis of fossil pollen from sites near treeline. The reconstruction from western Canada, including the Tuktoyaktuk Peninsula and the Mackenzie River Basin, is based on the work of Ritchie (1976; 1977; 1984; 1985), Ritchie and Hare (1971), MacDonald (1983; 1987a), MacDonald and Ritchie (1986) and Spear (1983). Studies by Nichols (1967a; 1967b; 1970; 1975) and Kay (1979) form the basis for the central Canada chronology which comprises the eastern District of Mackenzie and the Keewatin District. Pollen diagrams by Short and Nichols (1977), Lamb (1980; 1984; 1985), Richard et al. (1982) and Engstrom and Hansen (1985) were used in the reconstruction of eastern Canada consisting of the Labrador-Ungava region.


^{14}C yr BP $(\cdot 10^3)$
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
West
Modern Vegetation this zone is marked by a decrease in
Picea Forest (continuous)
Forest Tundra (shrub *Betula*)
Herb Tundra
Glaciation
Central
Modern Vegetation (cooling)
Boreal Forest (expansion)
Glaciation
East
Modern Vegetation (expansion of tundra)
Picea Zone
Shrub Tundra *shrub *Betula* & later *Alnus*
Open Tundra
Glaciation

and Ritchie, 1986; and Spear, 1983) have been responsible for the majority of the palaeoecological research on the Holocene in this area. Ritchie (1984) provides a recent synthesis of this work.

A study of modern pollen spectra from the forest, the forest-tundra and the tundra in the Mackenzie Delta reveals that modern pollen assemblages, from lake sediments, but not moss polsters, are representative of the vegetation (Ritchie, 1974). It is also reported that these modern assemblages are similar to those described in northern Manitoba by Lichti-Federovich and Ritchie (1968). MacDonald and Ritchie (1986) used principal components biplots and discriminant analysis to demonstrate that modern pollen assemblages from different vegetation zones in the western interior were mathematically distinguishable from their associated pollen rain. The recognition of how modern vegetation is portrayed in the pollen record has provided the basis for vegetation reconstructions from fossil pollen.

The fossil pollen records from the western interior of Canada have consistently indicated a similar pattern of post-glacial vegetation change. Vegetation reconstructions reveal that immediately following deglaciation, ~14 000 BP-~11 000 BP, tundra vegetation became established. Some areas supported herb dominated tundra while others were immediately inhabited by dwarf-<u>Betula</u> (birch) shrub tundra. Ritchie (1984) attributed variations in the early vegetation to location in relation to the Beaufort Sea and remnant ice, as well as edaphic conditions. By ~11 500 BP the importance of dwarf-Betula had increased, resulting in widespread shrub tundra. The rapid expansion of shrub Betula has been explained by climatic warming (Ritchie, 1984; 1985). MacDonald (1987a), however, observed that increases in shrub Betula occurred first in the most northern regions and later in more southerly regions. This led him to suggest that the expansion of Betula, especially in the central Mackenzie River Basin, was caused by a combination of climatic conditions and proximity to refugia. In this case the northern refugia being the unglaciated portion of Yukon and Alaska.

Tundra was replaced by forest at ~9 500 BP when there was an invasion by Picea, first by Picea glauca (white spruce) and then by Picea mariana (black spruce). Palynological evidence of a Picea expansion is supported by macrofossil evidence including the discovery of in-situ tree stumps (Spear, 1983). Such forest expansion is consistently reported to be the result of climatic warming (Ritchie, 1976; 1977; 1984; 1985; Ritchie and Hare, 1971; Ritchie et al., 1983; Spear, 1983 and MacDonald, 1987a). The early expansion of forest vegetation in western Canada was used as evidence in support of the Milankovitch theory of a thermal maximum at 10 000 BP in the high northern latitudes (Ritchie et al., 1983). The asynchronous increase in Picea in central Canada has been explained by an amplification of the long-wave disturbance of the westerlies concurrent with a more southerly placement of the arctic front than at present (Ritchie and Hare, 1971). In more recent studies autoecological responses, changes in wind patterns and interactions between species have been shown to be effecting the patterns of forest development (Spear, 1983; Ritchie, 1984; 1985, Ritchie and MacDonald, 1986 and MacDonald, 1987b).

After ~6 000 BP forest vegetation declined at sites near the western Canadian treeline along the arctic coast, while Alnus (alder) expanded. This was soon followed by the establishment of present-day tundra vegetation in areas such as Tuktoyaktuk Peninsula. The deterioration of the forest vegetation has been attributed to a period of slow cooling accompanied by an increase in fire frequency (Ritchie, 1984; 1985). This created openings in the forest which provided favorable habitats for the expansion of Alnus and other tundra elements (Ritchie, 1984; 1985). Increased moisture availability, resulting from climatic deterioration and edaphic changes, may have helped facilitate this increase in Alnus (MacDonald, 1987a; b). The establishment of modern vegetation represents the onset of present climatic conditions (Ritchie, 1984).

Central Canada

Numerous studies from central Canada have attempted to reconstruct past environments in the treeline area. However, there are several criticisms regarding various techniques, as well as interpretations, which weaken the palaeoecological exegesis (Ritchie and Hare, 1971). It should be noted that the studies included in this section are geographically proximal to the thesis study area.

The most well known palynological studies produced in central Canada were undertaken by Nichols (1967a; 1967b). Peat samples were collected from a forest-tundra site near Ennadai Lake, Keewatin and a forest site near Lynn Lake, Manitoba. The pollen records extend back to ~6 000 BP and ~6 500 BP respectively. The following interpretations relate all changes in the pollen record directly or indirectly (through fire frequency) to climate. No other parameters, edaphic conditions, biological interactions, hydrological conditions, or autecology, are considered.

Deglaciation was followed by the rapid development of forest vegetation; there is no evidence of the existence of tundra or shrub tundra in the early pollen record (Nichols, 1967a; 1967b). Between ~5 000 BP to ~3 500 BP the climate was warmer than present and forest vegetation existed at least as far north as the northern end of Ennadai Lake. Charcoal influx at ~3 500 BP indicates that a fire destroyed the forest at this time; coincident climatic cooling prevented the re-establishment of forest cover. Temperatures continued to decrease from this time until the present except for a brief period, from ~1 500 BP to ~ 600 BP, when they increased slightly. Modern vegetation was not established until ~ 600 BP. The pollen record from Ennadai Lake is characterized by fluctuating pollen percentages. Nichols (1967a; 1967b) indicates that this is caused by a proximal and unstable arctic front. The varying charcoal concentrations are explained by inconsistent fire frequency, also due to a shifting front. Other work by Nichols (1970; 1974; 1975) from central Canada report almost identical results. In addition Sorenson et al.(1971) and Sorenson (1977) described a history of arctic front fluctuations from paleosols which was similar to Nichols (1967a; 1967b; 1970; 1975). Kay (1979) produced pollen diagrams which also demonstrated a considerable likeness to this previous work.

Although these studies present similar results there are several criticsms that should be noted. First, all pollen records are derived from peat deposits. Pollen records constructed from peat profiles include a high proportion of pollen from plants growing on the peat and therefore are highly sensitive to local variations (Ritchie, 1974). One species particularly important in the treeline at Ennadai Lake is *Picea mariana*, which prefers moist, peaty areas. *Picea* is known for its ability to produce copious amounts of pollen. It is possible that the changes in *Picea* recorded in these diagrams represent small changes in a few local populations. Nichols (1967a; 1967b) explains the 'saw-tooth' pattern of the *Picea* pollen frequency at Ennadai Lake as representing a shifting arctic front. However, Jacobson and Bradshaw (1981) discuss the 'spiky' nature of pollen frequency and PAR diagrams for peats as being a result of: 1) an uneven distribution of plants growing on peats; 2) differential growth rates of peat through time; and 3) inaccurate sampling of peat. The third possibility is unlikely, since the patterns are not represented at Lynn Lake (Nichols, 1967a; 1967b). However, the first two explanations are plausible.

Another problem noted by Ritchie and Hare (1971) is that Nichols' (1967a; 1967b; 1970) conclusions are largely based on fluctuations of *Sphagnum* (peat moss) spores, a procedure which involves some tenuous assumptions. Also, in Nichols (1967a; 1967b; 1970) earlier studies, no correlations are made between modern vegetation and how it is represented by modern pollen. This leads to a weak vegetation reconstruction. Ritchie and Hare (1971) similarily note that "the interpretation of the pollen frequencies is equivocal, particularly in light of data on modern pollen assemblages from the tundra, forest-tundra, and the Boreal forest of Central Canada" (pp. 333).

It is possible to reconstruct past environmental conditions (especially climate) by direct comparisons of modern pollen assemblages to fossil pollen assemblages (Andrews et al., 1980). Qualitative estimates of July temperature (Nichols, 1967a; 1975) inspired quantitative calculations of past July temperatures using transfer functions (Kay, 1979; Kay and Andrews, 1983 Andrews and Diaz, 1981; Andrews and Nichols, 1981, and Andrews et al., 1981). Transfer functions are determined from modern relationships between pollen and climate. Basically, they are a mathematical function which can be applied to a fossil pollen assemblage to estimate past climatic variables. The modern pollen is generally interpreted using principal components analysis. Transfer functions are then derived by relating the modern pollen to the modern climate using a multiple regression technique or canonical correlation.

The results from studies estimating past July temperatures for central Canada using transfer functions (Kay, 1979; Kay and Andrews, 1983, Andrews and Diaz, 1981; Andrews and Nichols, 1981; and Andrews et al., 1981) are similar to the qualitative estimates by Nichols (1967a; 1975). Transfer functions indicate that over the last 6 000 years the mean July temperature has varied ±2-4 ° C from the modern mean. In general, these studies indicate the following trends for past mean July temperatures:

i) Prior to ~5 000 BP temperatures were cooler;

ii) Between ~5 000 BP and ~3 500 BP temperatures were warmer; and

iii) from ~3 500 BP to the present temperatures declined.

Andrews and Nichols' study (1981) is the most contradictory to these generalizations. They found that mean July temperatures were warmer from ~5 500 BP to ~4 000 BP. Then from ~4 000 BP to ~3 000 BP the July temperature fell below the modern July mean, while from ~3 000 to ~2 000 BP they were above it. Following ~2 000 BP the temperatures declined.

A number of criticisms of these studies should be noted. The first problem involves the use of PCA in the statistical analysis. Using this technique the fossil pollen samples which do not have 'real' modern analogues may be erroneously linked to modern pollen assemblages in the first few principal components or canonical variates (Overpeck et al., 1985).

Another weakness in these particular studies is the use of modern pollen collected from different deposits than those from which the fossil pollen was collected. It has been demonstrated that within a given vegetation zone the signal produced by pollen deposited in lakes is different to that produced by pollen deposited in peat (Jacobson and Bradshaw, 1981; Ritchie, 1984). Yet Kay (1979) and Kay and Andrews (1983) use modern pollen from lake sediments to compare to fossil pollen from peat. In another study the average of a suite of moss polsters is used to derive a modern pollen signal comparable to a lake sediment sample (Andrews and Nichols, 1981). This is then used to compare to unadjusted fossil peat pollen deposits.

Finally, although it has been stated that transfer functions provide a reasonable estimate of palaeoclimates (Bryson, 1985), the failure to include other factors (edaphic and hydrological conditions, autecology, fire and biological interactions), or to consider the complex interactions between these variables, must be viewed as a serious inadequacy of this technique.

In summary, palynological investigations near treeline in central Canada are based on pollen collected from moss polsters, which are not as representative of regional vegetation as lake sediments (Jacobson and Bradshaw, 1981; Ritchie, 1974). Palaeoecological reconstructions have continually focussed on determining past climatic conditions (especially temperature), and have failed to acknowledge that several other variables may have affected the distribution of vegetation, both in space and time. The use of several statistical procedures to determine transfer functions have been employed to determine palaeotemperatures from fossil pollen. These studies use various techniques which result in consistently similar results. However, the validity of these studies is questioned.

Eastern Canada

The review of eastern treeline sites will be brief because although palynological work began as early as 1947 (Werner, 1947), few radiocarbon dated diagrams have been produced north of treeline (Short and Nichols, 1977). Recent studies that have examined vegetation changes in the forest transition, including several near the forest limit, will be discussed (Short and Nichols, 1977; Lamb, 1980; 1984; 1985; Richard, et al., 1982 and Engstrom and Hansen, 1985)

Modern pollen analysis, using principal components analysis, demonstrate that vegetation zones are distinguishable via pollen samples from Labrador lakes (Lamb, 1980). The separation of vegetation zones, using modern pollen samples, is more successful in eastern Canada than in other studies from near treeline. This may be due to the exclusion of sites near vegetation transitions (Lamb, 1980).

The treeline history summarized in figure 2 has been reconstructed from the works of Short and Nichols (1977) Lamb (1980, 1984, 1985); Richard et al. (1982); and Engstrom and Hansen (1985). Vegetation existing prior to ~9 000 BP was typical of herb tundra environments. The timing of the establishment of vegetation in Labrador varied from ~10 300 BP- ~5 600 BP, as a result of the complex history of deglaciation as described by Ives (1957) and more recently by Dyke and Prest (1987). Following ~9 000 BP until ~5 000 BP shrub tundra dominated the area. Most studies conclude that the invasion of tundra by Alnus and shrub Betula was a result of climatic amelioration (Short and Nichols, 1977; Lamb, 1980). By ~5 000 BP forest vegetation had developed at sites in the modern forest-tundra zone of Labrador (Short and Nichols, 1977). The seemingly long delay in the forestation of Labrador has been noted by Lamb (1980; 1985) and Short and Nichols (1977). Lamb (1980) explained the slow expansion of spruce as a result of a geographical barrier, the Gulf of St. Lawrence and/or the persistance of remnant glacial ice in northern Labrador. His arguments negate equilibrium of forest vegetation with climate at this time. Contrary to this, Short and Nichols (1977) hypothesize that forest vegetation expanded as a result of climatic warming and that the delay in climatic amelioration was caused by the influence of maritime air.

It is not surprising that there are opposing views regarding historical treeline/climate relationships, since the present day relationship is unresolved. Elliott (1983) found that Picea at its northern limits produced viable seeds. Therefore, she concluded that these stunted northern trees were at their 'environmental' limit rather than their climatic limit. Studies at the Quebec treeline indicate that trees are found to be capable of reproducing sexually; but just north of treeline they only reproduce asexually (Payette, 1983; Payette and Gagnon, 1979; 1985). Therefore, it was concluded that the northernmost populations of Quebec trees are out of equilibrium with climate and are, in fact, relict stands surviving in conditions beyond their ecological tolerance. Until the controversial results regarding the present northern limit of trees is resolved, it is unlikely that the factors controlling the historical limits will be understood.

Another interesting observation pertaining to the _Picea_ zone in several Labrador pollen diagrams is that there is a clear pattern of tree succession in the late Holocene. _Picea glauca_ established first and was replaced later as the dominant species by _Abies balsamea_. _Picea mariana_ dominated this forest vegetation following _Abies balsamea_ (Lamb, 1980; Engstrom and Hansen, 1985). This succession is believed to be the result of deteriorating soil conditions caused by the accumulation of waterlogged peat. Engstrom and Hansen (1985) provide geochemical data to support this hypothesis. This succession could also be directly related to climatic change. However, _Picea_ and _Abies_ inhabit climatically analogous sites; their modern distribution appears to be more related to edaphic conditions (Engstrom and Hansen, 1985).

Tundra expansion as a result of climatic cooling occurred between ~4 000 BP and ~3 000 BP (Short and Nichols, 1977; Lamb, 1980; 1984; 1985; Richard et al., 1982; and Engstrom and Hansen, 1985).

1.6 Summary/Objectives

This review has synthesized present-day knowledge of post-glacial treeline history from western, central and eastern Canada. The general changes in treeline vegetation across Canada have followed similar patterns, although the chronology of these changes has varied. The interpretation of analogous vegetation changes has differed considerably from western to eastern Canada. The environmental variable on which most attention has focussed is climate, but edaphic and hydrological conditions, fire, autecology, and biological interactions are also considered in the interpretations from western and eastern Canada.

In view of the current state of knowledge regarding the northern treeline in Canada the main objectives of this study are:

i) to reconstruct the past treeline vegetation from the central District of Mackenzie where it is not known;

ii) to compare the resulting vegetational history from this area to previously documented treeline histories from western, eastern and central Canada; and

iii) to identify the environmental factors that controlled vegetation change in the study area.

To achieve these objectives two cores from lakes located in the tundra were obtained. The fossil pollen, charcoal, and sediment stratigraphy was studied. Chronological control was provided by ^{14}C dating of organic material from the cores. Pollen analysis of twenty eight modern surface samples provided information regarding the representation of present-day vegetation in the pollen record. This was used to aid in the interpretation of the fossil pollen record.

CHAPTER 2 STUDY AREA

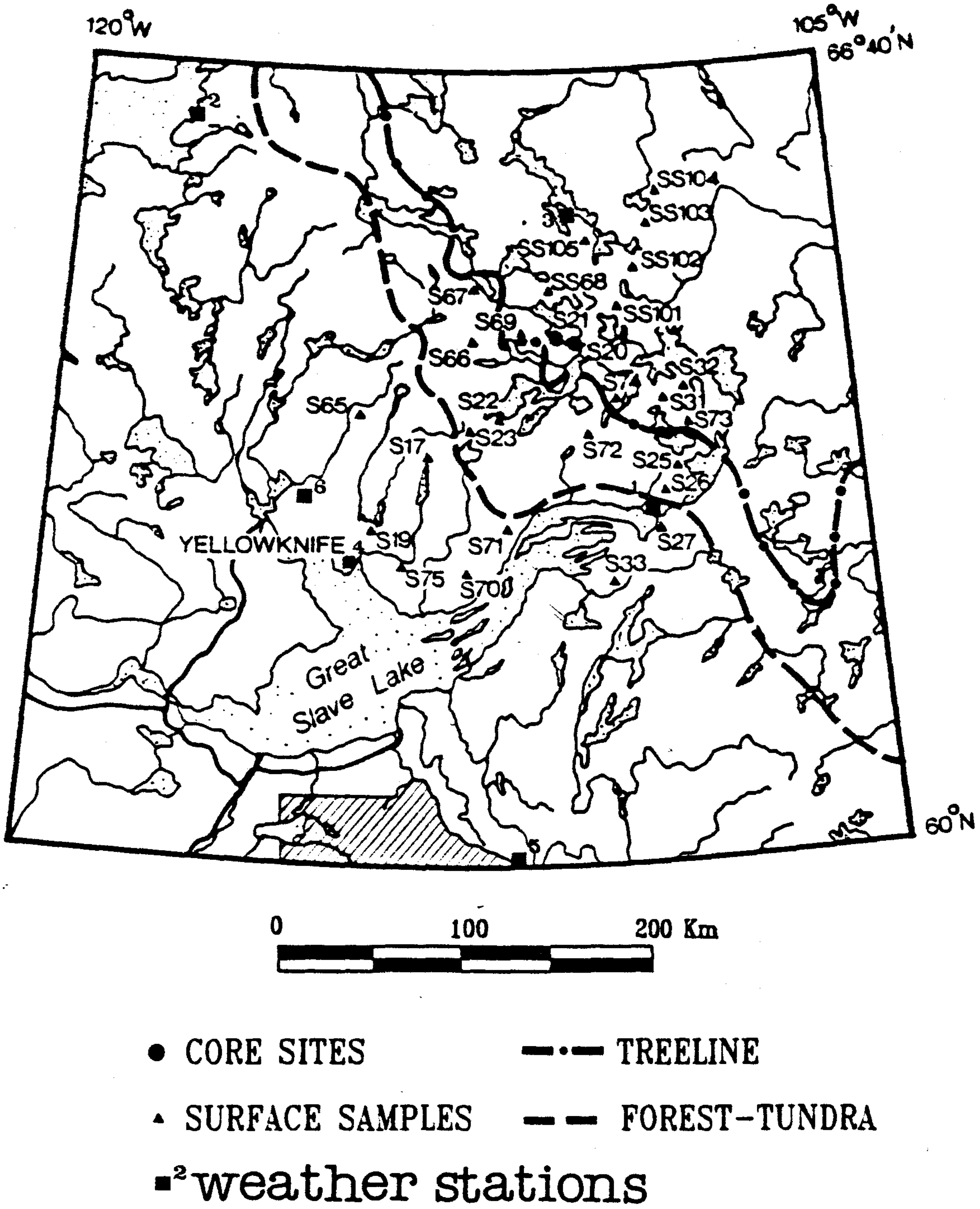
The study area lies northeast of Yellowknife, Northwest Territories and transects the forest, the forest-tundra and the tundra ecotones. The area is bound on the north by 65°00'N; in the south by 62°33'N; in the east by 108°06'W and in the west by 114°40'W (figure 3).

The study area is part of the Canadian Shield physiographic region which is typified by a rolling terrain with only a few tens of metres of local relief. The only exception is the eastern arm of Great Slave Lake which is characterized by some relatively rugged escarpments of >100m. The landscape is dominated by numerous lakes, which reflect a post-glacial drainage system. Regional drainage is south into the Great Slave Lake, which is then drained by the Mackenzie River.

2.1 Bedrock Geology

The study area lies in the Slave structural Province which has been relatively stable since the close of the Archean. The geological history is summarized by Henderson (1985). Basement felsic gneisses and plutonic rocks, are overlain by supercrustal rocks, which are part of the Yellowknife Supergroup, and can be described as terrigenous to volcanic clastic sediments metamorphosed to greenschist

Figure 3: **Map of the study area.** Core sites S21, McMaster Lake, and S20, Queen's Lake are denoted by circles, while sites where modern pollen has been collected are indicated by triangles. Squares indicate sites where climatic data was available (see table 1). The boundary seperating the tundra and the forest-tundra (treeline) and the boundary seperating the forest-tundra and the forest are indicated.


120°W
105°W
66°40'N
60°N
SS104
SS103
3
SS105
SS102
SS68
S67
SS101
S69
S21
S20
S66
S32
S7
S31
S65
S22
S73
S23
S17
S72
S25
6
S26
YELLOWKNIFE
4
S19
S71
S27
S75
S70
S33
2
5
Great Slave Lake
0
100
200 Km
● CORE SITES
▲ SURFACE SAMPLES
■² weather stations
TREELINE
FOREST-TUNDRA

and lower amphibolite facies. During the late Archaean and the early Proterozoic these rocks were intruded by granites varying in composition from granidiorites to potassic granites.

2.2 Glacial History

The study area was glaciated repeatedly during the Quaternary and glacial features, including well developed eskers and drumlins, are prominent components of the landscape. Glacial sculpture, characterizing the exposed bedrock, is another common feature of the study area. The most recent reconstruction of the deglaciation of the region (Dyke and Prest, 1987) provides the following chronology:

11 000 BP- the entire area is still covered by ice;

10 000 BP- The study area is partially covered by retreating ice and partially covered by glacial Lake McConnell;

9 000 BP- the area is ice free and glacial Lake McConnell is drained; however ice still exists only 50km away to the northeast;

8 400 BP- remnant ice is present 300km northeast of the study area;

8 000 BP- remaining ice persists 500km northeast from the study area;

6 000 BP-entire region of central Canada is ice-free.

2.3 Soils

Following deglaciation, relatively uniform soil conditions developed throughout the area. In general the soils are characterized by poor soil profile development except in the forests where podzols are observed (Sorenson, 1977). There is little development of soils in the study area immediately around Great Slave Lake where the landscape is dominated by rockland (Clayton and Marshall, 1974). Dystric brunisols are characteristic in the area northeast of the rocklands; and cryic regosols are typical north of this. These soil conditions are influenced by permafrost, which is continuous north of treeline and semicontinuous throughout the rest of the study area.

2.4 Climate

The study area is characterized by steep climatic gradients which result from large changes in meterological conditions north and south of the arctic front (Bryson, 1966). Significant changes in albedo from the tundra to the forest also cause differences in climatic variables (Hare and Ritchie, 1972). Table 1 lists normals for January, July, and annual temperatures, annual precipitation, degree days, and January and July wind speed and direction, for six locations within or near the study area (figure 3). Even within this small area, July temperature and degree days decrease significantly northwards from the forest towards the tundra. January temperatures, and precipitation are more uniform across the zones.

These normals describe a climate that is characterized by cold, harsh winters. High July temperatures in the forest result in hot summers; while moderate July temperatures in the tundra produce cool summers. Summers are short throughout the area (from 130 days in the forest to <90 days in the tundra). The small amount of precipitation results in a dry sub-humid climate. The shifting arctic front causes considerable cyclonic activity which produces lightening storms during the summer (Nichols, 1967a).

Table 1: **Climatic variables.** This table provides climatic data including normal January, July and annual temperatures, precipitation, degree days, and January and July wind speed and directions for six sites within the study area (see figure 3 for locations).

LOCATION	NORMAL TEMPERATURE JAN. (°C)	NORMAL TEMPERATURE JULY (°C)	NORMAL TEMPERATURE ANNUAL (°C)	PRECIPITATION (MM)	DEGREE DAYS	WIND JAN. (KM/HR)	WIND JULY (KM/HR)
1. Fort Reliance	-29.6	13.9	-7.0	253.8	1478.5	11.0 SW	10.9 NE
2. Port Radium	-27.6	12.4	-7.1	216.3	1307.4	9.0S	10.0S
3. Contwoy Lake	-32.1	9.7	-12.0	251.3	825.0	10.0S	16.8NW
4. Yellowknife	-28.8	16.3	-5.4	266.7	1771.5	13.7NW	16.1S
5. Fort Smith	-26.8	16.0	-3.3	349.3	1951.5	11.3NW	11.8NW
6. Snare Rapids	-30.0	16.1	-6.3	274.5	1715.1	N/A	N/A

2.5 Vegetation

Three vegetation zones are included in this area:

i) the forest;

ii) the forest-tundra; and

iii) the tundra.

The forest is typified by boreal, or taiga vegetation. It is characterized by a closed or continuous canopy. The main tree species on poorly drained sites are *Picea mariana* and *Larix laricina* (tamarack). *Picea glauca* and *Pinus banksiana* (jack pine) are common on well drained sites. *Betula papyrifera* (paper birch), *Populus tremuloides* (trembling aspen), and *Populus balsamifera* (balsam poplar) can also be found on well drained sites within the forest zone.

Moving northward, the forest is confined to areas with particularly favourable conditions, often along the shores of lakes and rivers. The result is patches of forest interspersed with natural openings. Drift ridges and hills populated by *Picea mariana* form forest 'patches'. *Picea glauca* and *Larix laricina* can also be present. The open areas consist of bog and barren rock which are inhabited by shrub *Alnus crispa* (green alder) and *Betula glandulosa* (glandular shrub birch) as well as *Salix* (willow), and diverse sedges, grasses, herbs, and lichens. The boggy areas often include stunted *Picea mariana* with an understory of herbs, including *Myrica gale* (sweet gale), and *Sphagnum* (peat moss) species (Larsen, 1980).

Further north, the forest all but disappears leaving the open expanse of the tundra. The only remnant of the forest are lone individuals, or small clusters of stunted prostrate *Picea mariana*. The prevalent vegetation includes *Alnus crispa*, and *Betula glandulosa*, *Salix*, grasses, sedges, herbs, as well as mosses and lichens. Vegetation in low lying areas is consistently dominated by members of Cyperaceae (sedge family), especially *Carex* (sedge). On upland sites, characterized by exposed bedrock, herbs, and a variety of lichens are important. Shrub species, *Alnus crispa*, *Betula glandulosa*, and *Salix*, are supported on the intermediate slopes, often in hollows where snow accumulates.

CHAPTER 3 METHODS

3.1 Field Methods

Pollen samples from modern lacustrine sediment were collected from a network of 28 small lakes that included sites in each of the three vegetation zones. Information regarding the size and location of the these lakes is provided in table 2 and figure 3. The lakes were chosen from topographic maps and aerial survey. Lakes having a small to medium size (at least 2ha) were selected to ensure that the dominant pollen component was regional rather than local (Jacobson and Bradshaw, 1981). The selection of large lakes (>100ha) was limited to avoid a large proportion of extra-regional pollen. (Jacobson and Bradshaw, 1981; Prentice, 1985). However, because most of the sampling was done in the summer the choice of lakes was restricted to those accessible by plane. Therefore a number of larger lakes were sampled and the results were included. The absence of inflow and outflow streams was also an important criteria.

Sixteen samples were collected using a free-fall cup sampler. Eleven samples were collected by Dr. G.M. MacDonald during the summer of 1985; the other five samples were collected by C. Larsen during the summer of 1987. The upper sediment of cores collected from the area by Dr. G.M.

Table 2: **Sample site locations.** This table lists the lakes from which study samles were collected. The longitude and latitude, elevation, size, depth and vegetation are provied.

SITE NUMBER	LATITUDE	LONGITUDE	ELEVATION (m)	SIZE (ha)	DEPTH (m)	VEGETATION
SS75	62°33′	113°55′	200	4	2.0	Forest
S19	62°44′	113°57′	300	5	1.8	
S33	62°16′	109°33′	360	2	6.5	
S18	62°56′	113°26′	360	4	2.0	
SS70	62°33′	112°05′	390	300	9.0	
SS65	63°18′	114°40′	280	100	4.0	
S27	62°38′	108°57′	360	1	8.0	
S17	63°19′	112°59′	420	8	4.0	↓
SS71	63°07′	111°05′	390	250	9.0	Forest-Tundra
S23	63°27′	112°28′	420	2	1.5	
S22	63°42′	111°57′	420	35	11.0	
S26	63°02′	108°37′	390	6	3.5	
SS72	63°23′	109°55′	390	300	4.0	
SS66	63°52′	112°52′	360	50	8.0	
SS67	64°32′	112°05′	440	150	7.0	
S25	63°12′	108°28′	390	3	3.0	↓
SS69	64°16′	111°17′	420	100	3.0	Tundra
S31	63°43′	109°09′	390	2	6.8	
SS74	63°50′	109°36′	390	90	17.0	
SS73	63°33′	108°17′	390	380	8.0	
S32	63°44′	108°06′	390	5	4.0	
SS101	65°08′	109°50′	495	75	N/A	
SS68	64°45′	110°33′	460	240	6.0	
SS102	65°18′	108°35′	450	200	N/A	
SS105	64°28′	109°20′	480	200	N/A	
SS103	65°05′	108°31′	450	190	N/A	
SS104	64°48′	108°55′	435	150	N/A	↓

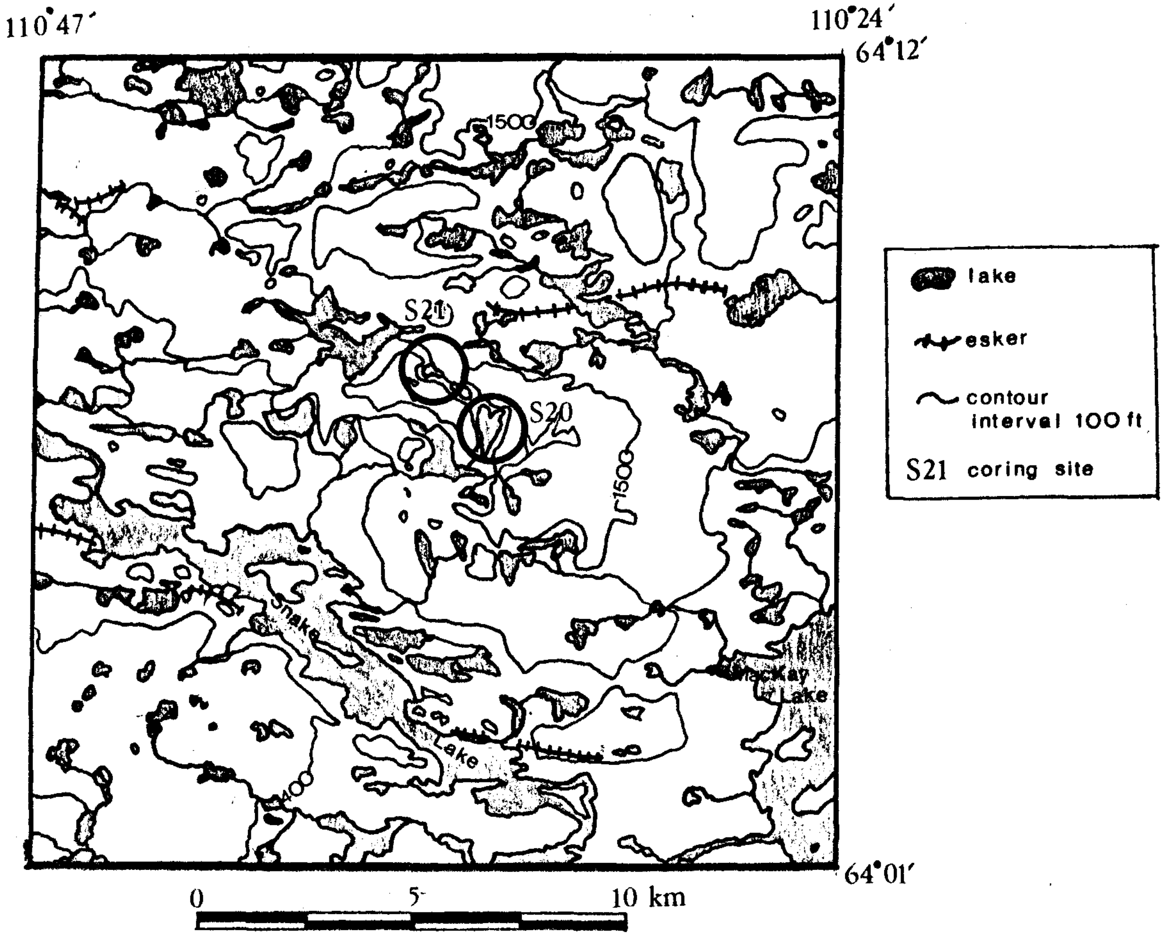
MacDonald during 1985, 1986 and 1987 provided another ten samples.

To obtain data regarding the vegetational history of the region two cores were extracted from lakes in the tundra vegetation region. The cores were raised in April, 1986 using a modified Livingstone piston corer (Wright et al., 1984). Coring was completed while the lakes were still frozen so that the ice could be used as a platform from which to work. The depth and area of the lake, as well as the surrounding vegetation, were noted. Topographic maps were used to determine appropriate coring sites. The criteria used to select lakes for coring were the same as those used to chose lakes from which to collect modern pollen samples. Tundra sites were chosen since one of the aims of this study is to determine if treeline has migrated north of its present position following the last glaciation. Such a change would only be reflected in the fossil pollen record of tundra lakes. Two cores from lakes located 2km apart were studied to provide a means to verify that the pollen stratigraphy represented conditions beyond the immediate vicinity of the individual lake.

The two cores, S21 and S20, were removed from lakes informally designated McMaster Lake and Queen's Lake respectively. McMaster Lake is located at 64°08'N, 110°35'W while Queen's Lake is located approximately 2km southeast at 64°07'N 110°34'W (figure 4). Both lakes are at an elevation

Figure 4: **Location of coring sites.** This detailed map provides information on the topography and surrounding landscape at McMaster and Queen's Lake.

CORING SITES



of 480m asl. McMaster Lake is small with an area of =12ha and a depth of =8m. Queen's Lake is considerably larger and shallower with an area of 50ha and a depth of 3.5m. The vegetation around both is characterized by _Carex_ fell fields. Some small _Picea_ sparsely populate the area around Queen's Lake; but none are located near McMaster Lake.

3.2 Laboratory Procedures

Dating

Radiocarbon dates were obtained on bulk organic sediment from sections of the core which, from preliminary pollen analysis, appeared to be near important changes in the pollen record. The core from McMaster Lake (S21) was ~65cm and samples for dating were taken at 10cm, 20cm, 30cm, 40cm and 60cm depths. Samples were taken at 15cm, 45cm, 60cm and 100cm depths from the Queen's Lake core (S20) which was ~119cm long. A twig found at 105cm in the Queen's Lake core was also dated. The sediment that was dated was not calcareous and contained no pre-Quaternary pollen or spores. The bulk organic sediment from McMaster Lake and a twig from the Queen's Lake core were dated by atomic mass spectrometry at the Isotrace Laboratories of the University of Toronto. Radiocarbon dating of the sediment from the Queen's Lake core was done by the Radiocarbon Laboratory at the Department of Earth Sciences at the University of Waterloo.

Pollen Analysis

The McMaster Lake and Queen's Lake cores were subsampled at intervals of 2.5cm and 5.0cm respectively. This provided 27 samples from McMaster Lake and 23 samples from Queen's Lake. One ml of sediment was prepared for pollen analysis following the procedure described by Faegri and Iverson (1975). Two calibrated and pretreated *Lycopodium* tablets were added to each of the subsamples from the McMaster Lake core, while one tablet was added to each of the subsamples from the Queen's Lake core and to each of the subsamples of modern pollen sediment. The addition of the *Lycopodium* tablets provides a means to calculate the palynomorph concentration (Stockmaar, 1972).

By combining information regarding the sedimentation rate with the palynomorph concentration it becomes possible to estimate the pollen accumulation rate (PAR) (Davis, 1967). Sedimentation rates were estimated for McMaster and Queen's Lake by plotting radiocarbon dates on depth *vs* age graphs and estimating the slope of relatively straight-line segments with linear regression.

All of the samples were treated with HCl, KOH, and HF to remove calcium carbonate, humic acid, and siliceous matter, respectively (Faegri and Iverson, 1975). It was necessary to use hot HF for a period of 90 minutes, stirring every 20 minutes, to dissolve all of the silica. Cellulose was removed by acetolysis. Fine material remaining in the samples after the chemical treatment was removed by fine seiving (Cwynar et al., 1979). The samples were then treated with safarin dye and mounted on slides in silicon oil (2 000 cs).

Following the guidelines in Birks and Gordon (1985) a minimum of 300 terrestrial grains were counted for each sample. The only exception being the bottom sediment sample in the core from McMaster Lake, where the pollen concentration was so low that only 150 grains could be counted. Identification of the pollen was made using the guides of Kapp (1969), McAndrews et al. (1973), and Bassett et al. (1978) and a modern reference collection. Morphological characteristics were used to distinguish *Picea mariana* from *Picea glauca* (Hansen and Engstrom, 1985). The diameters of *Betula* grains were measured to differentiate arboreal *Betula* from shrub *Betula*. A diameter of greater than 20um is often considered diagnostic of arboreal *Betula*; while a diameter of less than 20um is considerd to be diagnostic of shrub *Betula* (Ritchie, 1974). However, it is recognized that this criterion must be used with caution (Ives, 1977). Thirty *Betula* grains were measured for each sample. *Alnus crispa* pollen was distinguished from *Alnus incana* (speckled alder) by their individual morphologies as described by Richard (1970) and Hadden (personal communication, 1987).

From the fossil pollen counts relative pollen frequency and PAR diagrams were constructed. The pollen sum used in calculating the pollen percentages included all terrestrial pollen. The diagrams were subdivided into biostratigraphic units, referred to as pollen assemblage zones, which were based solely on changes in the pollen and spore content of the sediment (Birks, 1986). The delineation of the pollen diagram into pollen zones was done by visual inspection.

Modern pollen spectra were drawn from the modern pollen data. Sites from the same vegetation zone were grouped together and listed in order of their distance from treeline. The modern pollen sum also included all terrestrial pollen.

Charcoal Analysis

The total area of charcoal fragments contained in each sample was estimated using image analysis. This technique involves digitizing a single microscopic view. The area of the charcoal within this view is estimated by measuring the areas of a given gray level (optical) density, which includes only the dark coloured charcoal (MacDonald et al., 1988). Lycopodium grains from each view were also counted. Charcoal area was calculated for at least 100 views, or more if ten Lycopodium grains had not yet been observed. Charcoal concentration was determined by dividing the total area of charcoal for a given sample by the ratio of added to counted Lycopodium grains. Similar to PAR, charcoal accumulation rate (CHAR) was determined by dividing the charcoal concentration by the sedimentation rate.

Loss on Ignition

Loss on ignition (LOI) was used to determine the proportion of the organics and inorganics in the sediment of each of the subsamples (Dean, 1974). This procedure involves heating the sediment to 550 C for one hour, which results in the oxidation of the organic fraction. By measuring the change in weight from before and after the heating treatment, the amount of organic material in a sample can be estimated (Dean, 1974). The LOI results presented in this thesis should not be considered quantitatively, since they only represent relative changes in the organic content of the sediment.

3.3 Statistical Analysis

The taxa used in the numerical analysis of modern and fossil pollen included: *Picea mariana*, *Picea glauca*, *Pinus Betula*, *Alnus crispa*, *Alnus incana* (speckeled alder), *Salix*, *Myrica gale*, *Shepherdia canadensis* (soapberry), Ericaceae (heath family), *Artemisia* (wormwood), Chenopodiaceae-Amaranthaceae (Cheno.-Am) (goosefoot family and Amaranth family), Cruciferae (mustard family), Rosaceae (rose family), Gramineae (grass family), Cyperaceae, and *Sphagnum*.

Dissimilarity coefficents (DCs) were calculated to determine whether the three vegetation zones were mathematically separable in the modern pollen record, and whether these modern assemblages provided analogues for the fossil pollen assemblages.

A numerical value of the similarity between two given assemblages is provided by DCs; the smaller the value is, the greater the similarity between the two asssemblages. The similarity between modern pollen assemblages from different sites was determined using three measures:

1. the chord distance measure,
   $d_{ij} = \sum_k (p_{ik}^{1/2} - p_{jk}^{1/2})^2$;
2. the standardized Euclidean distance measure,
   $d_{ij} = [\sum_k ((p_{ik} - p_{jk})/s_k)^2]^{1/2}$; and
3. the Euclidean distance measure,
   $d_{ij} = [\sum_k (p_{ik} - p_{jk})^2]^{1/2}$,

where d_{ij}= the dissimilarity coefficent value between two pollen spectra i and j; p_{ik}= the proportion ($0.0 < p_{ik} < 1.0$) of the pollen type k in the pollen spectra i; s_k= the standard deviation of proportions for pollen type $k = (\sum_i (p_{ik} - p_{jk}/n)^2/n-1)^{1/2}$ (Overpeck et al., 1985).

The values of coefficents determined using the Euclidean distance measure (EDM) are most influenced by the more abundant pollen taxa (Overpeck et al., 1985). Small variations in rare pollen taxa have little influence. For the standardized Euclidean distance measure (SEDM) the more important pollen types are down-weighted, making the rare pollen types more influential (Overpeck et al., 1985). The chord distance measure (CDM) attempts to reduce 'noise' from random variations (Overpeck et al., 1985). Therefore, in CDM the rare pollen taxa are more influential than in EDM, but less than in SEDM.

The ability of each of these three methods to differentiate between forest, forest-tundra and tundra pollen assemblages was evaluated using the procedure outlined herein. DCs were determined for the following:

1. each tundra pollen assemblage compared to each and every other tundra zone;
2. each forest-tundra pollen assemblage compared to each and every other forest-tundra pollen assemblage; and
3. each forest pollen assemblage compared to

each and every other forest pollen assemblage.

A mean DC value for each of these groups was determined (i.e. all the DCs calculated from comparisons of tundra sites with other tundra sites was summed and divided by the total number of DCs). Since these comparisons were made between sites situated in the same vegetation zone it would be expected that the mean DCs would approch zero.

Next, DCs were calculated for the comparison of:

1. each tundra pollen assemblage to each forest-tundra assemblage;
2. each tundra pollen assemblage to each closed forest assemblage; and
3. each closed forest pollen assemblage to each forest-tundra assemblage.

Similar to above, the mean dissimilarity coefficent of each of these groups was determined. These comparisons are between pollen assemblages from sites located in different vegetation zones, so it would be expected that these values would be greater than the mean dissimilarity coefficents determined previously.

The 'best' technique (i.e. the one considered to most effectively distinguish pollen assemblages from unique vegetation zones) is the one which resulted in smaller mean DCs for comparisons of pollen assemblages from sites located in the same zone, and larger DCs for comparisons between pollen assemblages from different zones.

The 'best' results were used to determine the DCs of each modern pollen assemblage compared to each of the fossil pollen assemblages. For each fossil pollen assemblage a map depicting the sites from which the modern pollen assemblages were taken is provided. The DC determined between the given fossil pollen assemblage and each modern pollen assemblage is plotted at the site from which the modern assemblage was taken.

CHAPTER 4 RESULTS

4.1 Distinguishing Characteristics of Modern Vegetation Zones

The values of mean DCs calculated between modern pollen assemblages from the tundra, the forest-tundra, and the forest are listed in table 3. The contemporary pollen spectra are provided in figure 5. The mean *Betula* grain size for each site is found in figure 6, while histograms in figure 7 depict the relative frequency of these grain sizes. The relative frequency grain-size histograms for the fossil *Betula* pollen from McMaster Lake (figure 8) and Queen's Lake (figure 9) will also be discussed in this section. Figure 10 illustrates LOI results for the modern samples.

Changes in the vegetation across the forest-tundra transition are reflected in the numerical analysis, the modern pollen spectra, the *Betula* grain-size analysis, and the LOI results. Numerical analysis indicates that subtle changes exist between the three vegetation zones. Table 4 provides the resulting mean DCs for comparisons between sites from the same zone and from unique zones. It would be expected that the value of the mean DC calculated from comparisons between sites from the same vegetation zone would be less than between sites from unique zones. This is

Table 3: **Comparison of Euclidean, Standardized Euclidean and Chord distance measures.** This table gives the mean and standard deviation of dissimilarity coefficents of similar comparisons (eg. all comparisons made between the forest and the forest-tundra were summed averaged) using three techniques, A)CDM; B)EDM; C)SEDM . Each square provides the mean of the comparison with the vegetation zone in the corresponding row and column. It would be expected that the mean for comparisons made within the same zone (eg. tundra sites compared to other tundra sites) would have higher values than the mean for comparisons made between sites from different vegetation zones (eg. a forest zone with a tundra zone). However this only true for SEDM.

	Tundra	Forest - Tundra	Closed Forest
		A	
Tundra	x=0.13 S_x=0.07	x=0.15 S_x=0.06	x=0.15 S_x=0.08
Forest-Tundra	x=0.13 S_x=0.06	x=0.10 S_x=0.07	x=0.11 Sx=0.07
Closed Forest	x=0.15 S_x=0.08	x=0.11 S_x=0.07	x=0.08 S_x=0.05
		B	
Tundra	x=0.19 S_x=0.10	x=0.21 S_x=0.07	x=0.25 S_x=0.09
Forest-Tundra	x=0.21 S_x=0.07	x=0.15 S_x=0.07	x=0.19 S_x=0.07
Closed Forest	x=0.25 S_x=0.09	x=0.19 S_x=0.07	x=0.18 S_x=0.1
		C	
Tundra	x=4.4 S_x=1.6	x=4.8 S_x=1.0	x=5.0 Sx=1.3
Forest-Tundra	x=4.8 S_x=1.0	x=4.0 S_x=1.8	x=4.5 S^x=1.2
Closed Forest	x=5.0 S_x=1.3	x=4.5 S_x=1.2	x=3.6 S_x=1.7

the case when the SEDM is used. However, the EDM and CDM DC values are similar regardless of whether the sites being compared are from the same vegetation zone or not. This implies that distinctions between the pollen assemblages across the forest-tundra transition are slight. The fact that SEDM most effectively separates the three vegetation zones suggests that it is the less common pollen taxa which are important in differentiating these zones (Overpeck et al., 1985).

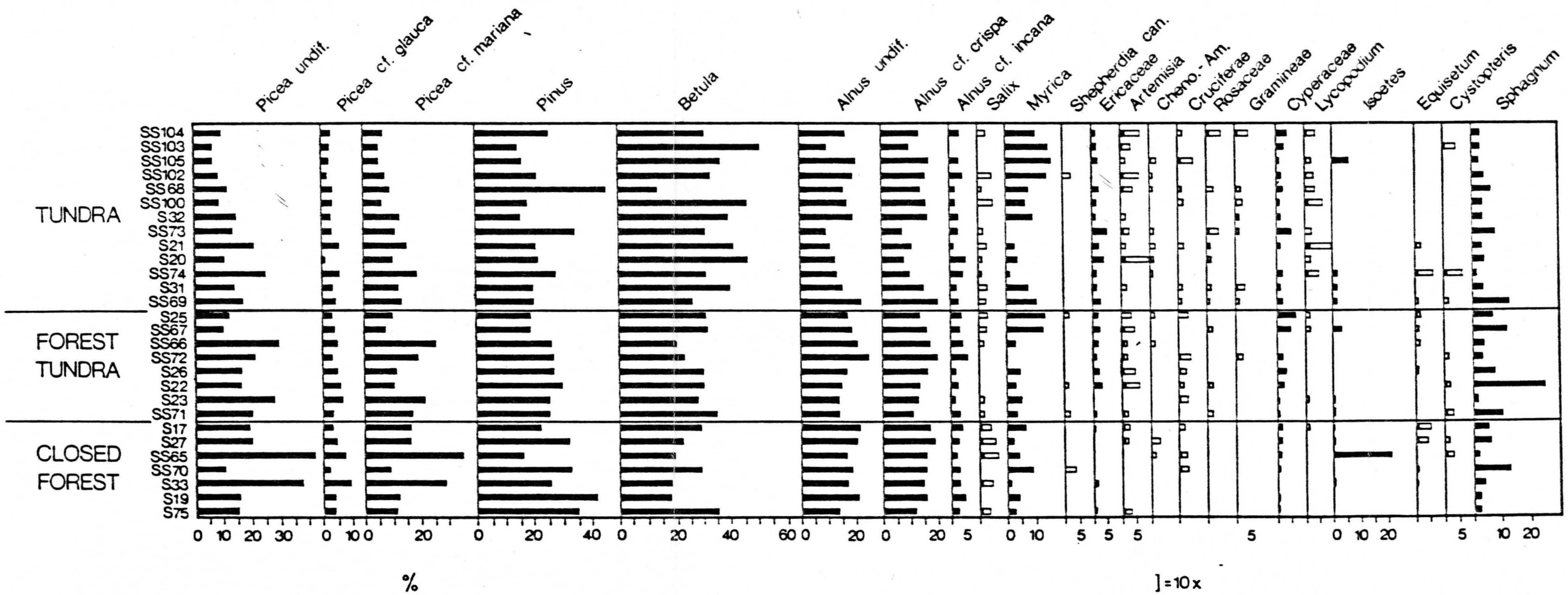
The modern pollen spectra depicts subtle differences as suggested in the numerical analysis. A description of the modern pollen assemblages from the forest, forest-tundra and tundra zones is presented below (figure 5).

Forest

The samples for the forest region are characterized by high values of Picea mariana (~15%) and Pinus (~25%) pollen. Although the amount of Picea glauca in the samples from the forest zone is small (~15%), it is still larger than the amount found in samples from the other two zones. Relatively low values of Betula (~24%), predominately with grain diameters of less than 20um, and Cyperaceae (~1%) also distinguish the forest zone from the other zones. Small amounts (<1%) of Ericaceae, Artemisia and Cheno.-Am., and the complete absence of Rosaceae and Gramineae further typify the forest samples.

Figure 5: **The modern pollen spectra.** Modern pollen spectra from twenty-eight sites are depicted. The sites are listed from north to south with reference to their distance from treeline. Note the relatively subtle changes in pollen assemblages for different vegetation zones.

SURFACE SAMPLES
Pollen Percentages



Forest-tundra

The most distinctive difference between the forest samples and the forest-tundra samples is an increase in several herb and shrub taxa and the first appearance of several other less common taxa. The proportion of samples containing Ericaceae, Artemisia, and Cyperaceae increases markedly in the forest-tundra. The average amount of these taxa increases to ~1-3%; ~1%; and ~1-4%, respectively. The presence of Rosaceae (~1%) and Gramineae (~1%) at some sites further distinguishes between the pollen spectra of these two vegetation zones. Another difference between the forest and the forest-tundra is an increase in Betula (~27%). The diameter of these grains continues to be, in general, less than 20um. It should be noted that there is little change in the amount of Picea mariana (~5%), Picea glauca (~5%), and Pinus (~24%).

Tundra

The tundra zone is delineated by an increase in Betula (~35%). The increase is largely composed of Betula grains with diameters of less than 20um. A marked decrease in Picea mariana (~10%) and Picea glauca (~3%) also typifies this zone. Many of the samples show a slight decrease in Pinus (~20%), however, some samples continue to contain large amounts of Pinus pollen. Several relatively common taxa, including Ericaceae, Artemisia, and Cyperaceae, do not change from the forest-tundra to the tundra. The number of sites containing Rosaceae, Gramineae and Cheno.-Am. increases in the tundra from the forest-tundra, although the quantity of these taxa at any given site remains low.

Several taxa are found in unvarying amounts in all three vegetation zones. These taxa are: *Alnus crispa* (~15%); *Alnus incana* (~4%); *Salix* (<2%); *Shepherdia canadensis* (~1%); Cruciferae (~1%); and *Sphagnum* (~5%).

Changes in the type (arboreal or shrub) of *Betula* pollen can also be used in distinguishing these vegetation zones (Ritchie, 1974). It is reasonable to expect arboreal *Betula* to decrease as one moves from the forest to the tundra and for shrub *Betula* to increase. Variations in *Betula* grain size have been used to distinguish arboreal *Betula* from shrub *Betula* and therefore aid in differentiating vegetation zones (Ritchie, 1974). In this study the mean grain-size measurement of *Betula* is less than 20um for all modern assemblages except two (figure 5). This implies that all modern *Betula* pollen is derived from shrub *Betula* which seems unlikely since arboreal *Betula* is found in the forest. Investigations of size-frequency histograms reveal that grain-sizes are clustered around 20um (figure 6). Ives (1977) demonstrated that shrub *Betula* does tend to have a smaller grain size than arboreal *Betula* although considerable overlap exists between the measurements of the largest shrub *Betula* grains and the smallest arboreal

Figure 6: **The mean Betula grain size.** The mean grain size of Betula, determined from diameter measurements of thirty grains, from modern samples and fossil samples is plotted. A grain size of less than 20um is considered shrub Betula, while a grain size of greater than 20 um is considered to be arborel Betula pollen. The surface samples are in order, starting from the top, of north to south. The mean grain size of Betula from all of the modern samples falls into the shrub Betula classification. The mean grain size of fossil Betula from Queen's Lake falls into the arboreal Betula group. At McMaster Lake the fossil Betula pollen is of shrub size at the base of the core, of arboreal size in the middle and of shrub size at the top.

BIRCH GRAIN SIZES

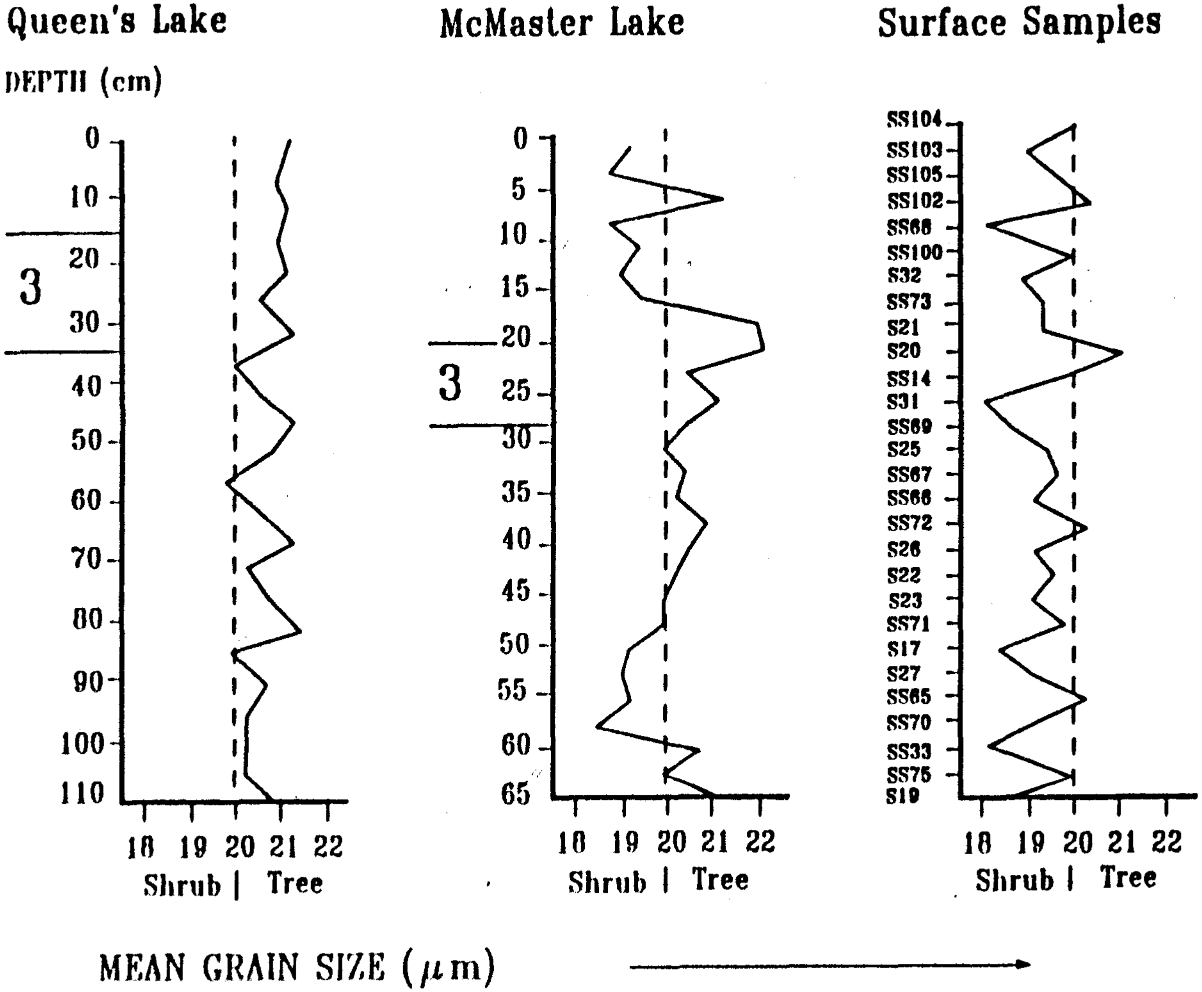
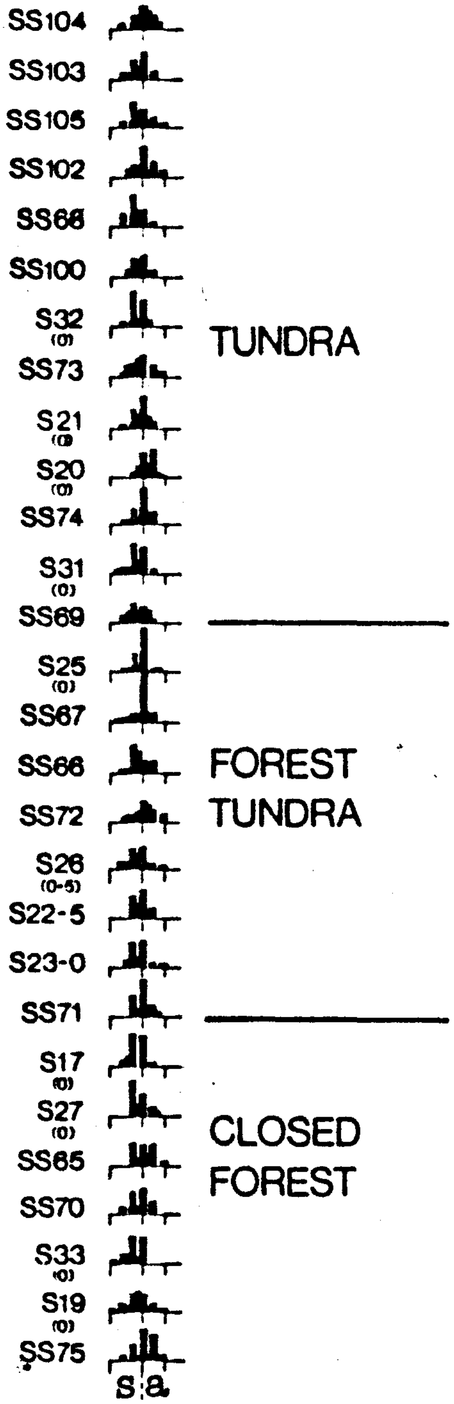


Figure 7: **Modern *Betula* Grain Size Histograms.** A series of histograms illustrates the grain- size/frequency relationship of *Betula* grains in modern samples. The centre hatch mark of each plot represents a size of 20 um and marks the division between shrub *Betula* and arboreal *Betula* (s=shrub; a=arboreal). Notice that the maximum frequencies are clustered around this line.

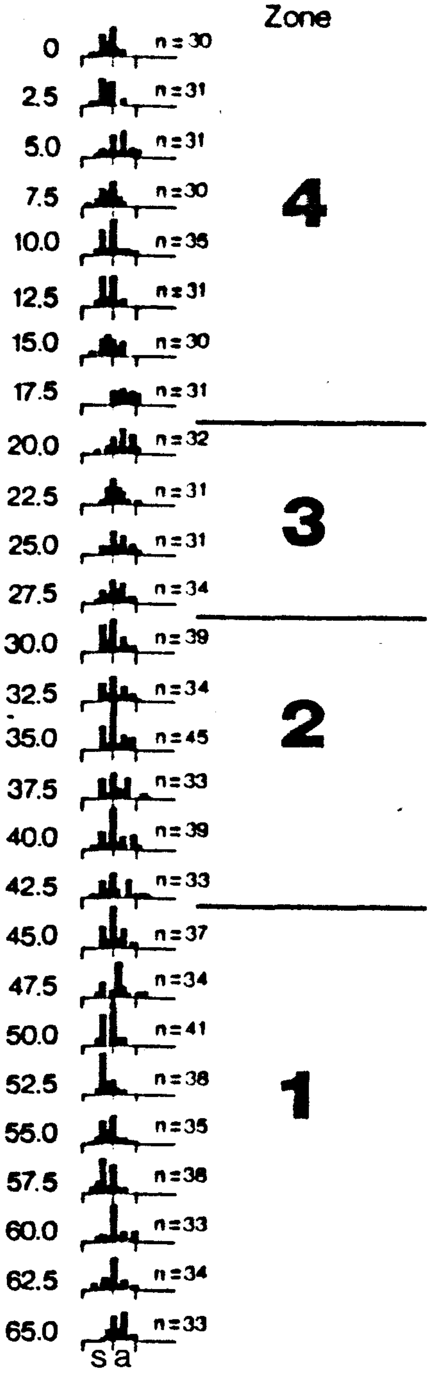
Surface Samples



SS-BIRCH GRAIN SIZES

Figure 8: **The McMaster Lake *Betula* grain-size histograms.** These histograms illustrate changes in the grain-size/ frequency relationship of *Betula* through time. The centre 'hatch' marks the division between arboreal and shrub pollen (s=shrub; a=arboreal). The grain-size with the maximum frequency shifts from shrub-size, to arboreal-size and back to shrub-size, from the bottom to the top of the core.

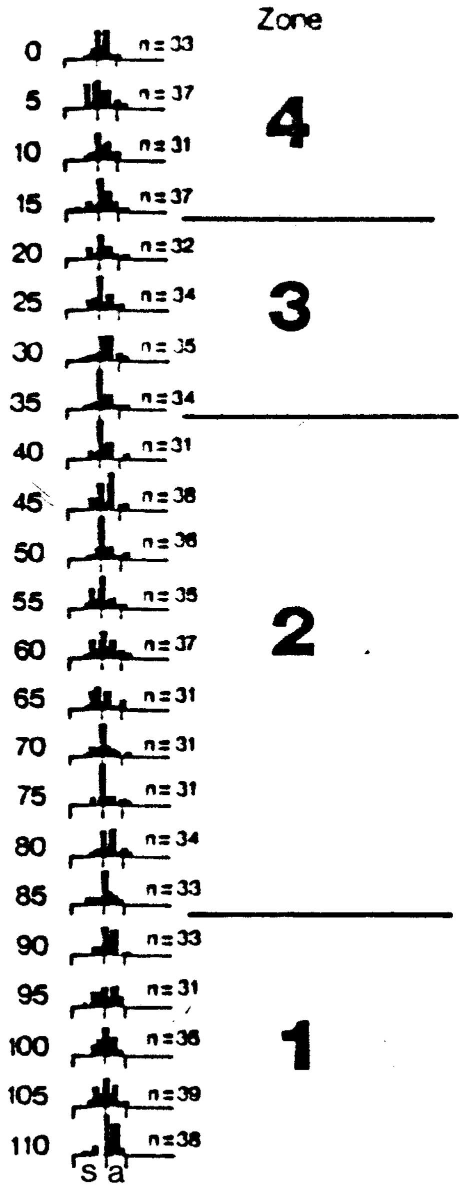
McMaster Lake 64°08', 110°35'



SS-BIRCH GRAIN SIZES

Figure 9: **Queen's Lake Betula grain-size histograms.** These histograms illustrate changes in the grain-size/frequency of Betula pollen through time. The centre 'hatch' marks the division between arboreal and shrub pollen (s=shrub; a=arboreal). The size with the maximum frequency tends to be close to the size seperating shrub Betula pollen from arboreal Betula pollen.

Queen's Lake 64°07'; 111°34'



BIRCH GRAIN SIZES

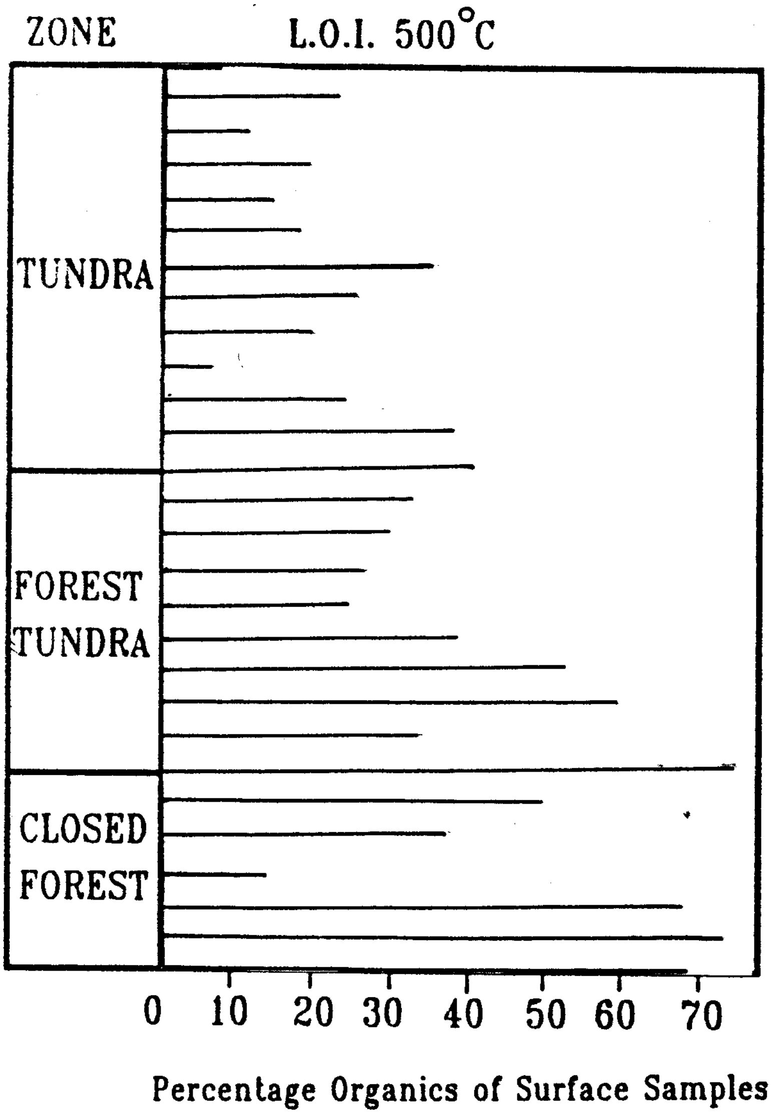
Betula. The size of the Betula grains, both arboreal and shrub, tend to be too close to the critical size of 20um for this to be a distinguishing criterion. This implies that it is not possible, based on grain-size, to distinguish arboreal from shrub Betula in the fossil record.

According to grain-size measurements, Betula deposited throughout the pollen record from Queen's Lake originated from arboreal Betula (figure 6 and 9). This is improbable since there is ample evidence to support the existence of a basal tundra zone where arboreal Betula could not have existed. The variations in Betula grain size from the bottom to the top of the McMaster core (figure 6 and 8) coincide with appropriate changes in vegetation. However, these fossil Betula measurements cannot be used to distinguish past vegetation zones because of the results from modern Betula analysis.

While the use of Betula grain size to aid in distinguishing between the modern vegetation zones proved unsuccessful, changes in the organic content of the sediment is useful in distinguishing the three ecotones. LOI results (figure 10) indicate that sediment deposited in the forest usually contains a high proportion of organic matter, while tundra sediment is commonly richer in inorganics. As might be expected the magnitude of the organic to inorganic ratio in the forest-tundra zone tends to be intermediate between these two.

Figure 10: **LOI results for modern sediment samples.** Sediment composition of modern samples indicated by LOI are illustrated. LOI provides qualitative estimates of the organic to inorganic ratio. Notice the general decrease in the organic content of sediment as one moves north from the closed forest to the tundra.

Percentage LOI at 500°C (Organic)



Numerical analysis reveals that subtle differences in the less abundant pollen taxa differentiate the forest, the forest tundra and the tundra. Differences in the proportion of organic to inorganic matter in the pollen sediment provides useful information, but changes in *Betula* grain size fails to distinguish the vegetation zones. The changes in organic content combined with the slight distinctions in the modern pollen spectra are sufficient to differentiate the modern vegetation zones in the modern pollen rain. This implies that it should be possible to distinguish similar zones in the fossil record.

4.2 Fossil Pollen and Sediment Stratigraphy

Chronology for this study was obtained from radiocarbon dating of bulk sediment samples and one twig. The dates are provided in table 4.

McMaster Lake

Four pollen assemblage zones were determined for the McMaster Lake core. These zones are depicted in figure 11, the pollen frequency diagram, and figure 12, the PAR diagram. Figure 6 illustrates the mean Betula grain size for each level while figure 8 provides histograms describing size-frequency distributions of these grains. The sedimentation rates, the LOI results and sediment stratigraphy are provided in figure 13, and the CHAR in figure 14.

Zone M1: (Betula-Cyperaceae Zone): 65-44 cm (~6 800-~5 500 BP)

This is the basal zone of the core and is dominated by Betula (~55%). The diameter of the Betula grains are generally less than 20um. Cyperaceae comprises ~5% of the pollen percentages. Alnus crispa and Alnus incana are present in amounts of ~3% and ~1%, respectively. At the very top of the core Alnus crispa increases to ~15% and Alnus incana increases to ~4%. Picea mariana is present in zone M1 in amounts of ~6-7%. Picea glauca exists in quantities of

Table 4: **14C Dates.** This chart provides information on the material used for dating and the lab where the dating was done. S21 is the core from McMaster Lake and S20 is the core from Queen's Lake.

Core	Depth (cm)	Material	Lab	Lab Number	Age (years BP)
S21	10	gyttja	Isotrace	TO-766	3 690±50
	20	gyttja	Isotrace	TO-158	3 680±60
	30	gyttja	Isotrace	TO-767	5 120±60
	40	gyttja	Isotrace	TO-156	5 360±70
	60	gyttja	Isotrace	TO-154	6 180±60
S20	15	gyttja	Waterloo	WAT-1770	3 820±60
	45	gyttja	Waterloo	WAT-1771	5 600±60
	60	gyttja	Waterloo	WAT-1772	6 150±60
	100	gyttja	Waterloo	WAT-1773	7 150±70
	105	twig	Isotrace	TO-827	7 470±80

Figure 11: **McMaster Lake pollen percentage diagram.** This diagram depicts changes in the relative percentages of fossil pollen from McMaster Lake. Four zones are defined. Zone 1, the *Betula*-Cyperaceae zone, is characterized by large amounts of *Betula* pollen. Zone 2, the *Betula*-*Alnus* zone, is delimited by a dramatic increase in *Alnus*. The third zone, the *Betula*-*Picea*-*Alnus* zone is distinguished by a marked increase in *Picea*, especially *Picea mariana*. Zone four, the *Betula*-*Pinus*-*Alnus* zone depicts the establishment of modern tundra vegetation. Note that the large *Pinus* percentages are due to an increase in exotic *Pinus* pollen.

McMASTER LAKE, N.W.T. 64°08′, 110°35′
Pollen Percentages

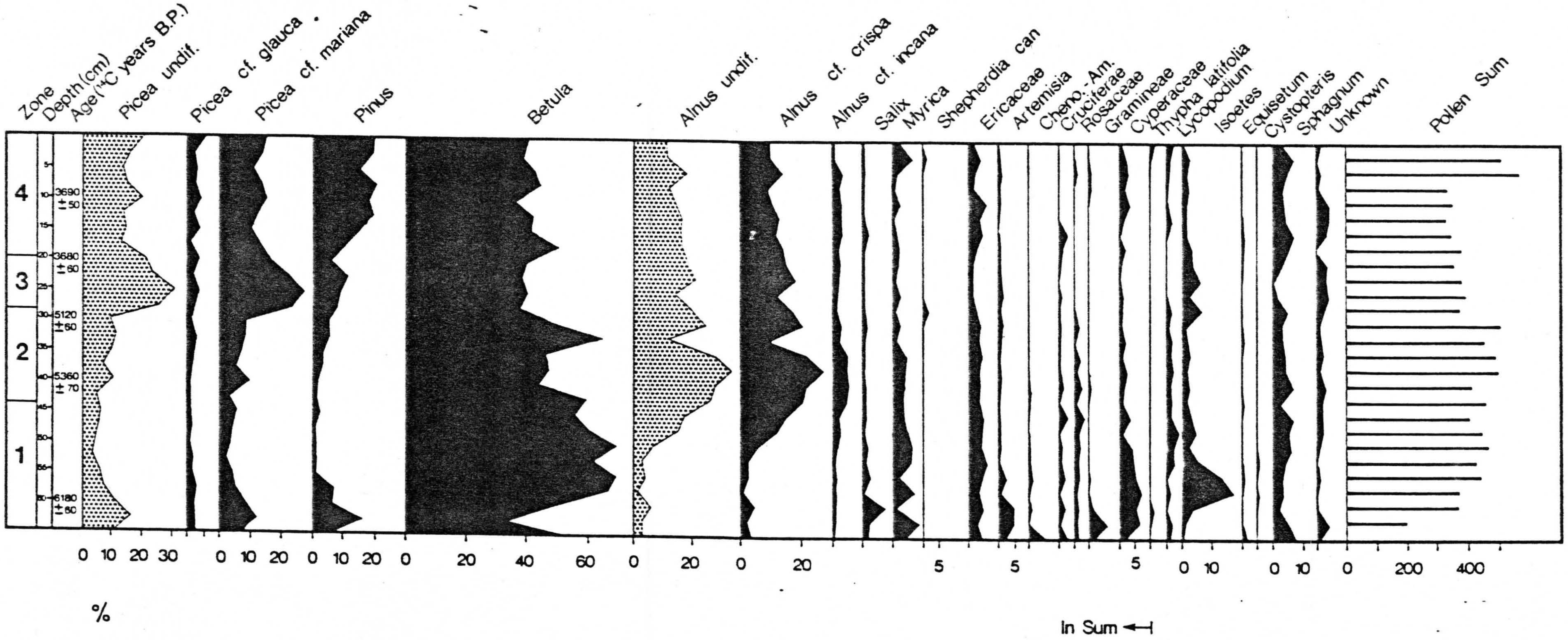


Figure 12: **McMaster Lake PAR diagram.** Changes in PAR through time are represented in this diagram. Four zones, illustrating similar trends to those described in the pollen percentage diagram, are distinguished. Note the sharp decrease in PAR of all taxa at the top of zone four. This may be reflecting sediment focusing.

McMASTER LAKE, N.W.T. 64° 08', 110° 35'
Pollen Accumulation Rates

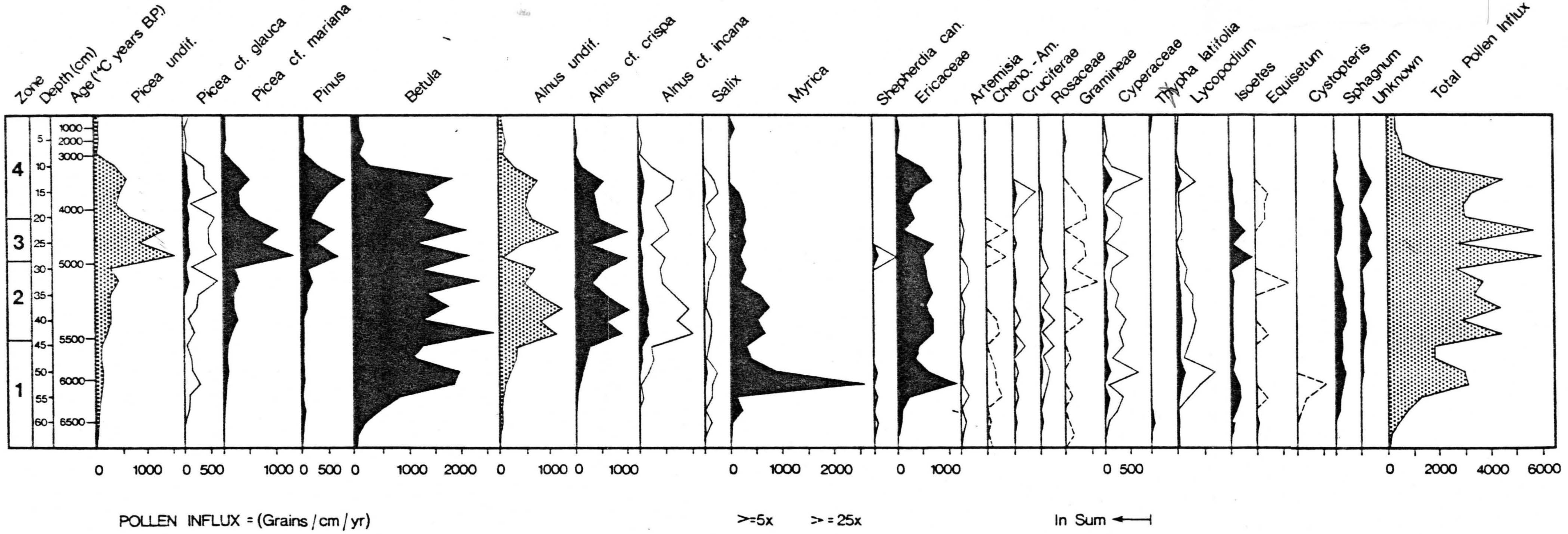


Figure 13: **Sediment information from McMaster Lake.** Information regarding the sediment composition and sedimentation rate is provided. From left to right, the first column depicts the vegetation zones described in the pollen percentage and PAR diagrams. The next column illustrates the sediment stratigraphy which depicts a change from sandy organics to algal gytjja near the base of the core. LOI results are provided in the next column. Note that the organic proportion reaches a maximum in zone 3. Finally a graph showing the sedimentation rate is shown. A decrease in sedimenation rate occurrs at ~3 690 BP. Table 4 provides information regarding the dates used in the construction of this graph.

SEDIMENTATION RATES
McMASTER LAKE (64°08', 110°35')

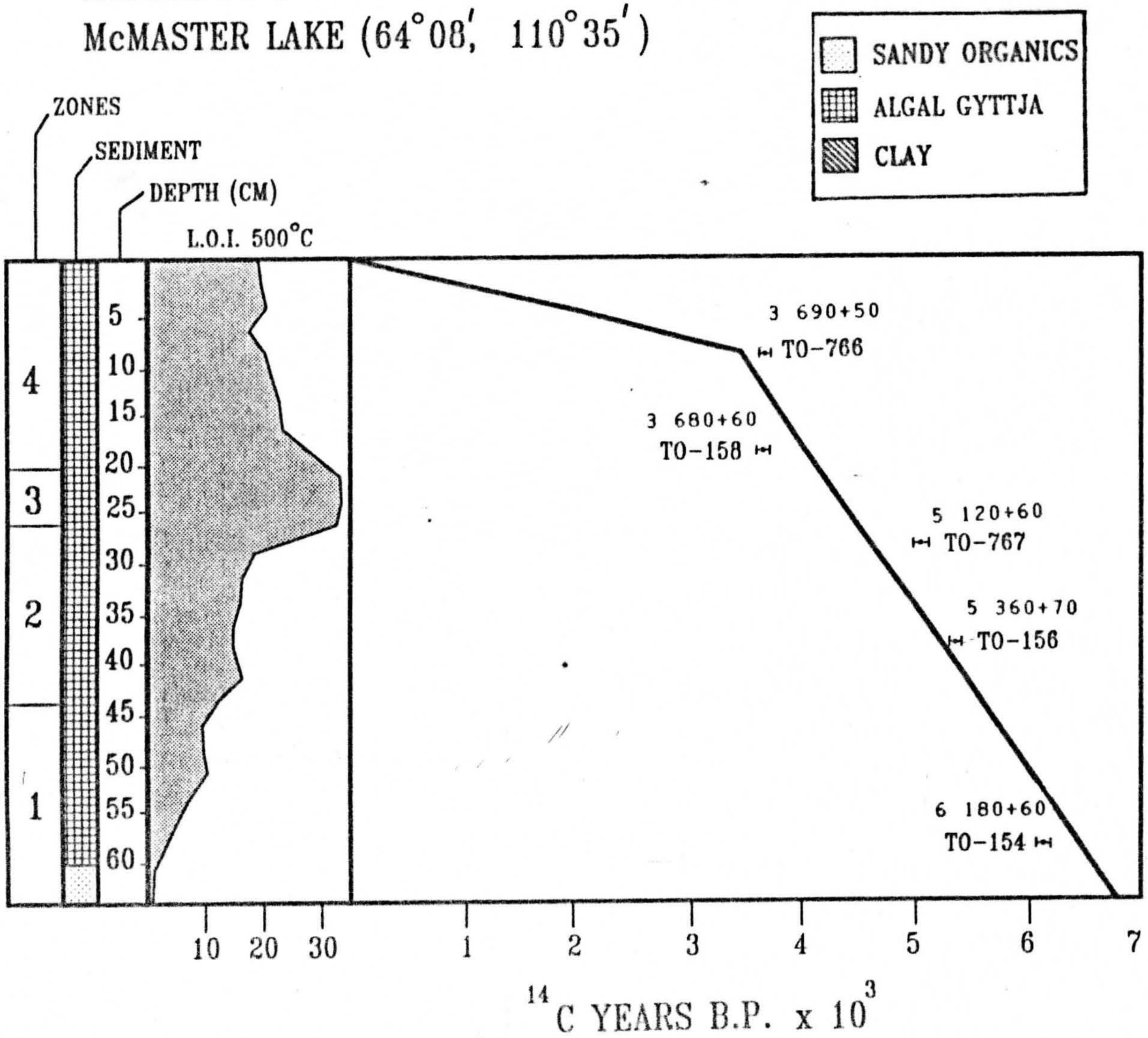
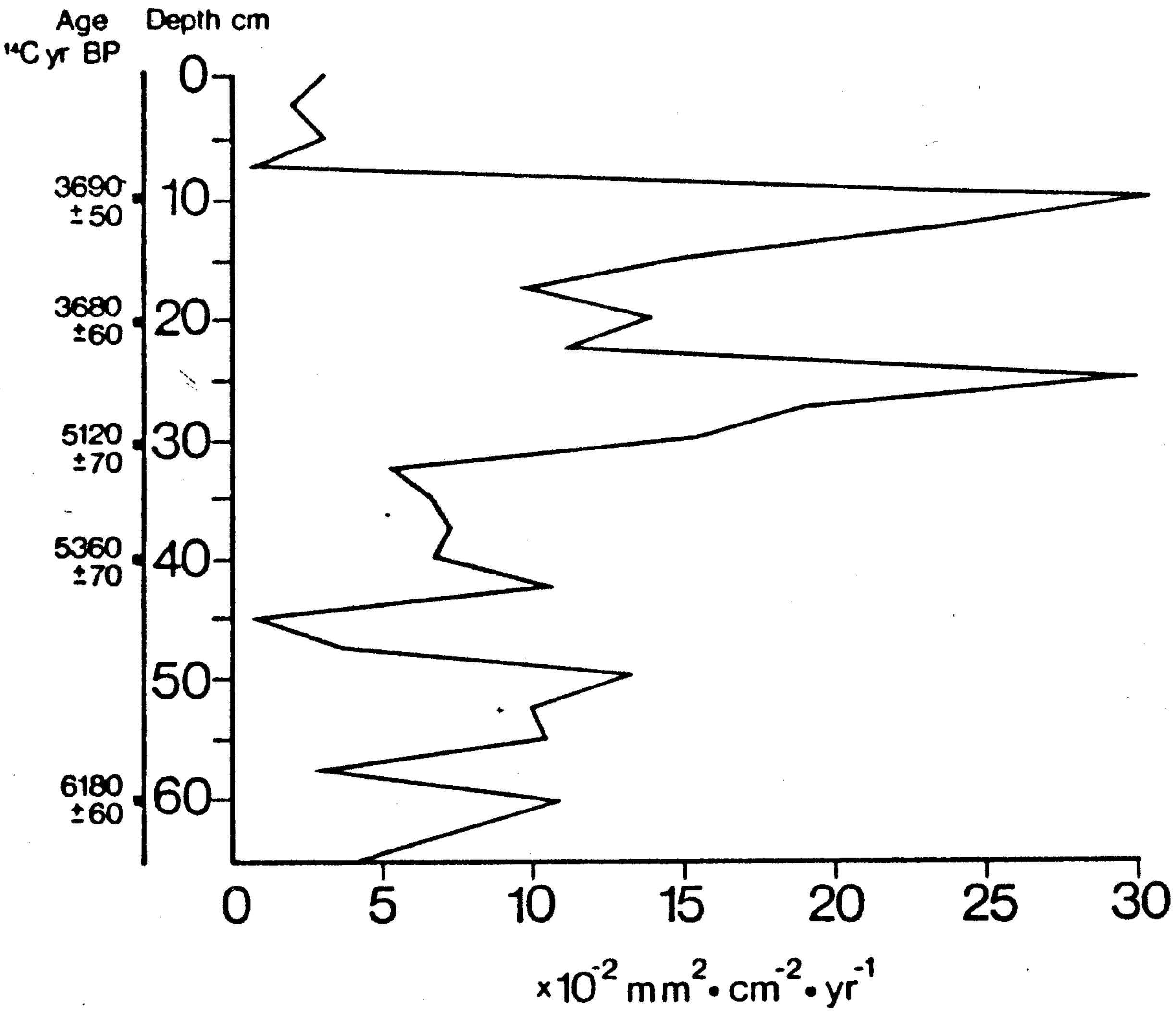


Figure 14: **Charcoal accumulation rate (CHAR) at McMaster Lake.** This graph illustrates changes in CHAR through time. Prior to ~5 000 BP CHAR remains fairly low. From ~5 000 BP to ~3 500 BP CHAR increases. Following ~3 500 BP it decreases.

Charcoal Influx McMaster Lake 64° 08', 110° 35'



~2%. There is ~1-15% *Pinus* in M1. Many of the herb and shrub taxa (*Salix*, *Artemisia*, Cheno.-Am., Rosaceae) and Gramineae reach maximum percentages (up to 5%) in this zone. Ericaceae is found in amounts of ~4% and *Myrica* in amounts of ~5%. There are traces of *Typha latifolia* (cat tail) and *Shepherdia canadensis*.

The PAR diagram depicts similar trends to those described in the pollen percentage diagrams, although the maximum percentages of the herb species is not reflected. PAR throughout this interval is low (~200 grains/cm/year to ~3 000 grains/cm/year). The CHAR is also low (~$8*10^2$ mm^2/cm^2/year). The sediment in this interval contains little organic matter. The sediment from the lower portion of this zone consists of sandy organics, which changes abruptly at 60cm to an algal gyttja.

Zone M2: (*Betula*-*Alnus* Zone): 44-28.5 cm (~5 500-~5 000 BP)

This zone is delineated by a sharp increase in *Alnus*. *Alnus crispa* increases to ~20%, while *Alnus incana* increases to ~5%. A decline in Cyperaceae to ~2% aids in distinguishing M2 from M1. *Betula* continues to be the dominant pollen type (~50%). The majority of the *Betula* pollen has a diameter of 20um. *Picea mariana* contributes ~7% of the pollen in this zone. *Pinus* shows a distinctive increase in this zone, beginning at ~2% at the bottom and increasing to ~7% at the top. The shrub and herb taxa, *Salix*, *Artemisia*, and Cheno.-Am., as well as Gramineae are only found in minute quantities (<1%). However, Rosaceae continues to be present in amounts of ~1-2%. *Shepherdia canadensis* and *Typha latifolia* are absent.

The trends in the pollen percentage diagrams, with the exception of the decrease in Cyperaceae, are reflected in the PAR diagram. The PAR increases from zone 1 to zone 2 to ~4 000 grains/cm/year. The CHAR remains relatively unchanged (7.5*10^2 mm^2/cm^2/year). The sediment is algal gyttja, and is slightly more organic than the sediment from the basal zone.

Zone M3: (*Betula*-*Picea*-*Alnus* Zone): 28.5-20 cm (~5 000-~3 680 BP)

This zone is delineated by a sharp increase in *Picea mariana* (~27%) and a decrease in *Alnus crispa*, *Alnus incana* and *Betula* to ~16%; ~2%; and ~34%, respectively. *Betula* grain diameters are generally greater than 20um. *Pinus* continues to increase, but does not exceed 12%. Finally, M3 is characterized by a decrease in Ericaceae to ~1-2%; of Rosaceae to <1%; of *Myrica* to ~1%; and of *Sphagnum* to ~2%.

Not all of the changes shown in the pollen percentage diagram are reflected in the PAR diagram. The decrease in *Betula*, *Alnus*, and *Sphagnum* is not evident. The PAR in this zone is relatively high (~4 500 grains/cm/year, but up to ~6 000 grains/cm/year). CHAR substantially increases reaching a maximum of $29*10^2$ mm^2/cm^2/year. Zone 3 contains the most organic matter of all the zones, and is composed of algal gyttja.

Zone M4: (*Betula*-*Pinus*-*Alnus* Zone): 20-0 cm (~3 680 BP to present)

A sharp decrease in *Picea mariana* (to ~13%), and a marked increase in *Pinus* (up to ~20%) distinguish this zone. Ericaceae and *Sphagnum* increase back to levels equivalent to those in M2. Cyperaceae also increases (from ~1% to ~2%). The largest amount of pollen continues to be *Betula*, generally with grain diameters of less than 20um (~43%). *Alnus crispa* and *Alnus incana* remain at levels of ~12% and ~3% respectively.

There are some interesting observations pertaining to the PAR diagram. Although the general trends discussed in the pollen percentage diagram are evident, all taxa have low and diminishing values from ~3 000 BP to the present. This is especially true of *Pinus*, which shows a continuous increase throughout M4 until ~3 000 BP when it dramatically decreases. The PAR decreases from ~4 000 to ~300 grains/cm/year in this zone. CHAR rises sharply to ~300*102 mm^2/cm^2/year at the bottom of the zone and then drops to ~4*102 mm2/cm2/year at the top. The sediment deposited from ~3 680 BP to the present was algal gyttja. The organic content of this sediment decreased from the bottom of the zone to the top.

Queen's Lake

Four pollen assemblage zones were determined for the Queen's Lake core. These zones are illustrated in figure 15, the pollen frequency diagram, and figure 16, the PAR diagram. Figure 6 illustrates the mean *Betula* grain size for each level while figure 9 provides the size-frequency histograms of the *Betula* grains. The sedimentation rates, the LOI results and the sediment stratigraphy are provided in figure 17 and the CHAR in figure 18.

Zone Q1: (*Betula*-Cyperaceae Zone): 110-87.5 cm (~7 400-~6 800 BP)

This is the basal zone of the core and is characterized by large amounts of *Betula* (~70%). The *Betula* generally have a grain size of more than 20um, and continue to be of this size throughout the core. Another common taxon in this zone is Cyperaceae (~6%). *Alnus crispa* and *Alnus incana* comprise ~3%, and ~2%, respectively, of the pollen percentage. *Picea mariana*, *Picea glauca*, and *Pinus* are present in small amounts (~5%; ~1%; and ~2%, respectively). The percentage of *Picea glauca* remains unchanged throughout the core. Herb species including *Artemisia*, Cheno.-Am., Cruciferae, and Rosaceae, reach maximum percentages (~1-2%). Ericaceae, *Myrica*, and *Sphagnum* are present in amounts

Figure 15: **Queen's Lake pollen percentage diagram.** This diagram illustrates changes in the relative percentages of fossil pollen from Queen's Lake. The four zones depicted in this diagram are the same as those described in the McMaster pollen percentage diagram.

QUEEN'S LAKE 64° 07', 110° 34'

Pollen Percentages

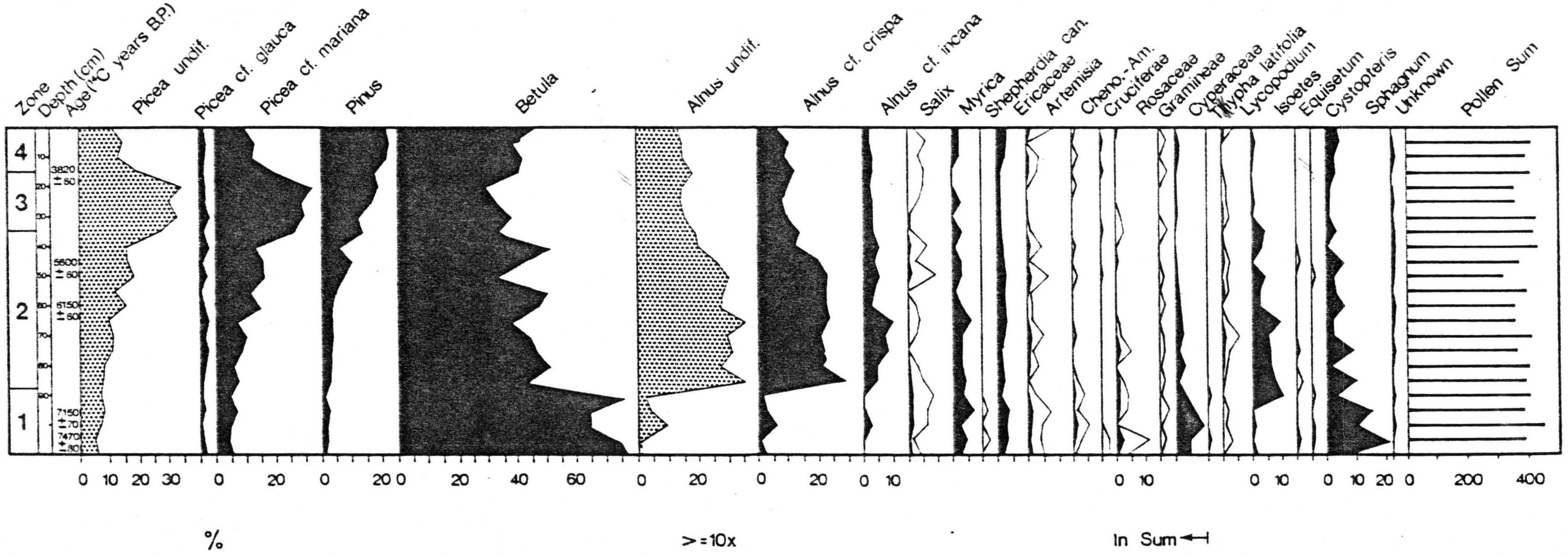


Figure 16: **Queen's Lake PAR diagram.** Changes in PAR through time are represented in this diagram. Four zones similar to those in the pollen percentage diagram are distinguished. However, some of the trends noted in the pollen frequency diagram are not evident here. This may be caused by a decrease in sedimentation rate as a result of sediment focussing.

QUEEN'S LAKE 64° 07', 110° 34'
Pollen Accumulation Rates

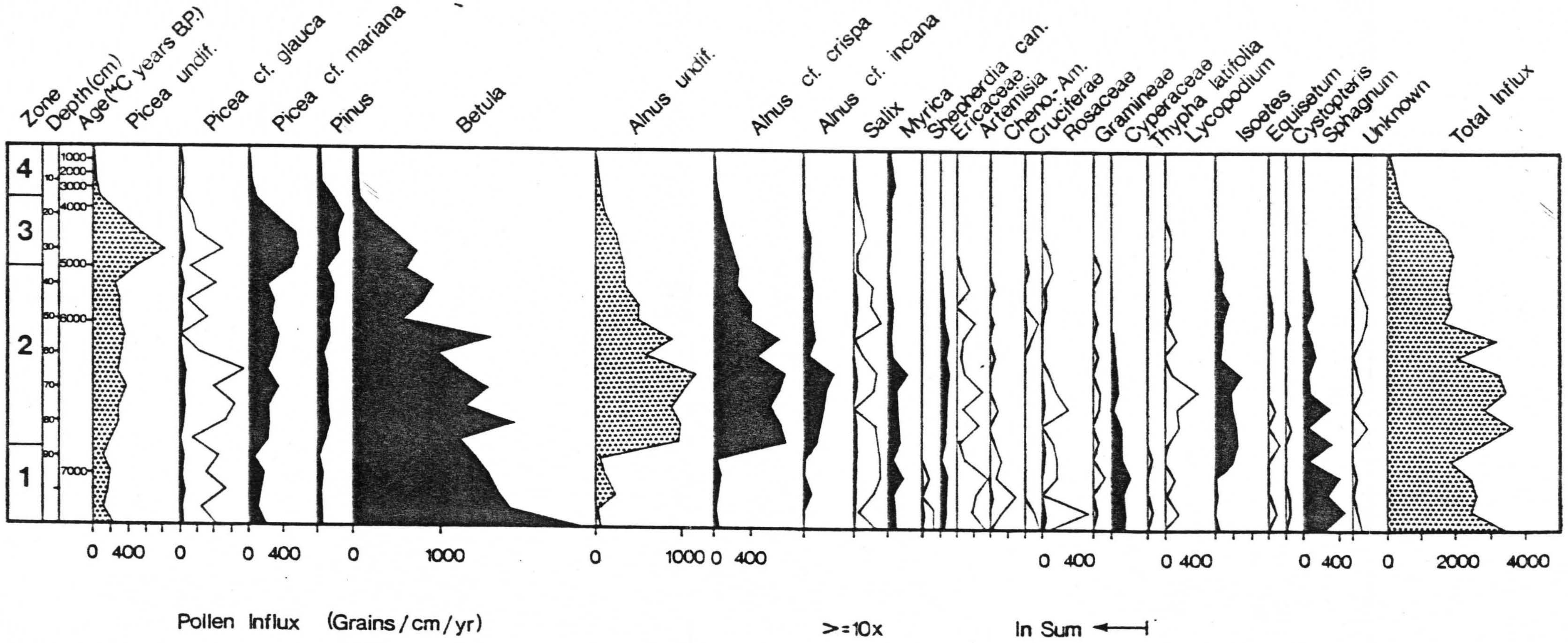
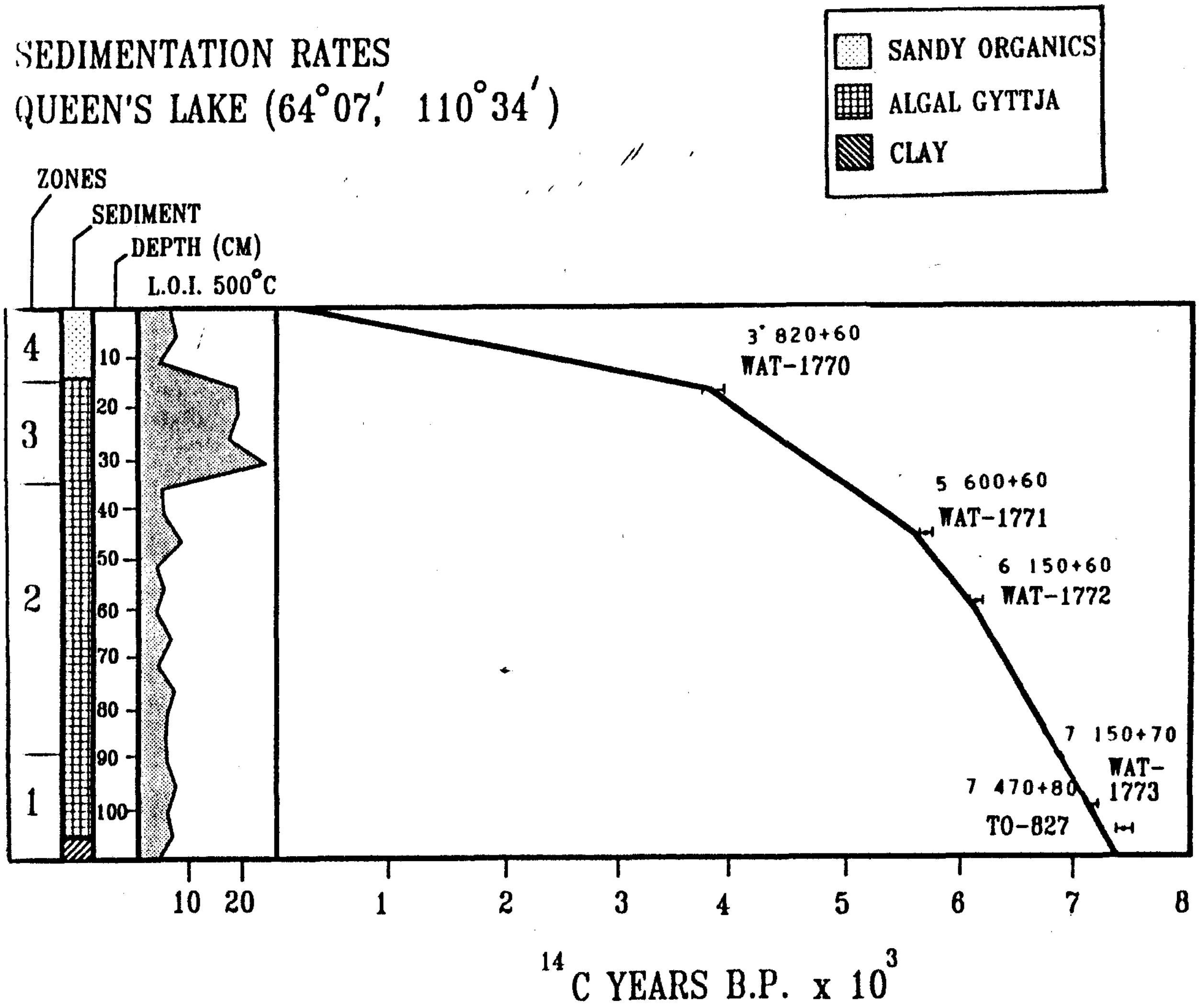


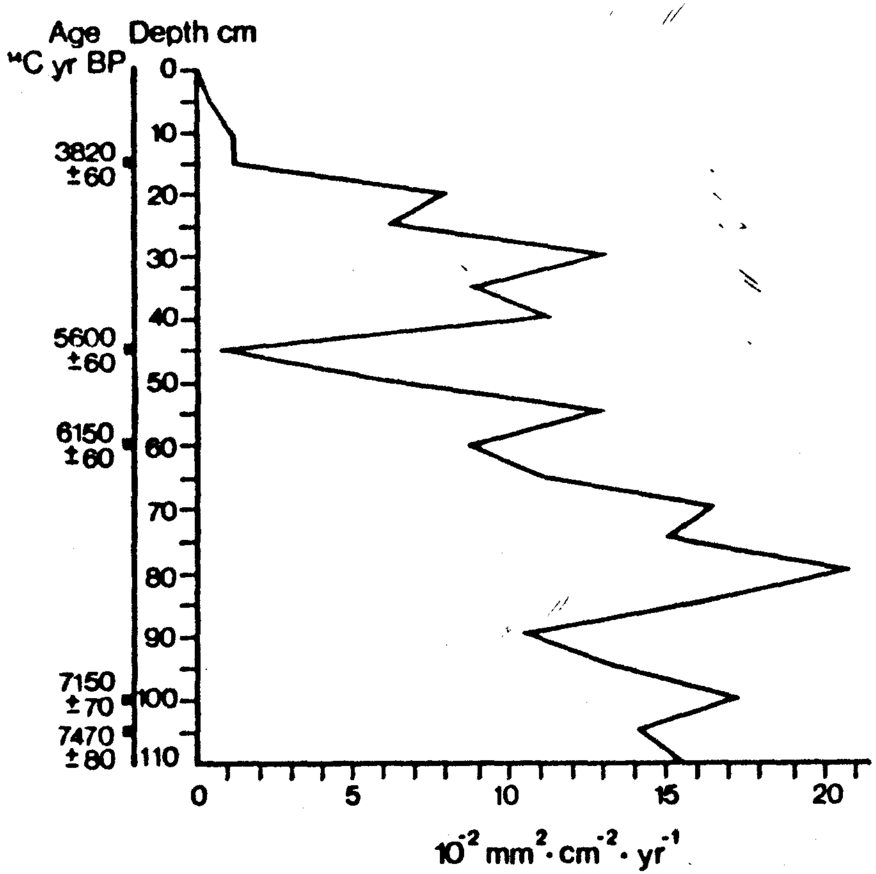
Figure 17: **Sediment information from Queen's Lake.** Information regarding the sediment composition and sedimentation rate is provided. From left to right, the first column depicts the vegetation zones described in the pollen percentage and PAR diagrams. The next column illustrates the sediment stratigraphy. Clay is overlain by a thick layer of algal gyjtta, which is covered by a relatively thin layer of sandy organics. LOI results provided in the next column indicate that the organic content of the soil reached a maximum in zone three. Sedimentation rates are shown to decrease from the bottom to the top of the core.



SEDIMENTATION RATES
QUEEN'S LAKE (64°07′, 110°34′)

Figure 18: **Charcoal accumulation rate at Queen's Lake.** This graph illustrates changes in CHAR through time. CHAR at Queen's Lake decreases from the bottom of the core to the top. This is similar to the decrease in sedimentation rate. It is likely that the CHAR is directly reflecting sedimentation as a result of sediment focussing and is not indicative of 'real' changes in charcoal concentration through time.

Charcoal Influx for Queen's Lake 64°07, 110°34



of ~3%; ~5%; and ~12%. There are traces of Typha latifolia and Shepherdia canadensis.

The trends in the pollen frequency diagram are clearly reflected in the PAR diagram. The PAR is quite large (~2 500 grains/cm/year). CHAR is also large (~14*102 mm^2/cm^2/year). The bottom of this interval is composed of clay, which abruptly changes at 107cm to algal gyttja. This sediment is composed of a high proportion of inorganics.

The most significant difference between zones Q1 and M1 concerns the chronology. M1 spans from ~6 800 BP to ~5 500 BP, and Q1 from ~7 400 BP to ~6 800 BP. A less important difference is the fact that at McMaster Lake the increase in Alnus occurs gradually, beginning in the upper portion of M1 and continuing through M2; while at Queen's Lake the change begins abruptly at the onset of zone Q2. Although Gramineae, Salix, and Cruciferae are present in both M1 and Q1, Gramineae and Salix reach a maximum in M1, while Cruciferae is the only one of these taxa that reaches a maximum in Q1. Another difference between the two cores is that in M1 there is a dramatic increase of PAR for all taxa towards the top of the zone, while in Q1 there is little change. Finally, the CHAR at Queen's Lake is, generally twice that of McMaster Lake.

Zone Q2: (Betula-Alnus Zone): 87.5-35 cm (~6 800-~5 000 BP)

The important feature of this zone is a dramatic increase of *Alnus crispa* and *Alnus incana* to ~25% and ~6%, respectively. This zone is also defined by a decrease in Cyperaceae to ~2%. *Betula* pollen diminishes, but it continues to be the dominant species (~45%). *Pinus* increases from ~3% at the bottom of Q2 to ~14% at the top. There is also an increase in *Picea mariana* throughout Q2 from ~7% to ~12%. The disappearance of *Typha latifolia* and *Shepherdia canadensis* also aids in distinguishing Q2.

The PAR diagram reflects most of these changes. However, the increase in *Pinus* and *Picea mariana* is only reflected from Q1 to Q2, but not through Q2. Also, the decrease in Cyperaceae is not reflected until the middle of Q2. The PAR in this zone increases slightly to ~2 750 grains/cm/year. CHAR during this period fluctuates considerably ($21*10^2$ mm^2/cm^2/year to $1*10^2$ mm^2/cm^2/year), but in general changes little from zone 1. Algal gyttja with a considerable amount of inorganics continued to be deposited during this interval.

Like M1 and Q1, the main difference between M2 and Q2 is one of chronology. M2 commences at ~5 500 BP and ends at ~5 000 BP, while Q2 spans from 6 800 BP to ~5 000 BP. In terms of pollen frequencies zone 2 of Queen's Lake is almost the same as zone 2 at McMaster Lake. The only differences are that *Sphagnum* decreases in Q2, but not in M2; and Rosaceae is insignificant in Q2, but is found in amounts of ~1-2% in M2. The PAR also differs between the two sites. It increases at both lakes, but the increase at McMaster Lake is 4x greater than at Queen's Lake.

Zone Q3: (*Betula*-*Picea*-*Alnus* Zone):35-15cm (~5 000 BP-~3 820 BP)

The characterizing feature of this zone is the abrupt rise of *Picea mariana* reaching a maximum of ~32%, although *Betula* remains the most common taxon (~35%). *Pinus* also increases (to a maximum of ~18%), but the increase is more gradual and continues into zone 4. *Alnus crispa* decreases dramatically from the preceding zone to ~12%, while *Alnus incana* decreases slightly to ~4%. The decrease of Ericaceae to 1%; of *Myrica* to ~2%; and of *Sphagnum* to ~2% further delineates Q3.

PAR reflects the above trends and remains at 2 000 grains/cm/year. Although CHAR is generally less than in zone 2, there is a significant peak reaching ~13.5*102 mm^2/cm^2/year. The sediment deposited during this period was algal gyttja, containing the greatest amount of organic material found in the sediment from this core.

Zone 3 of Queen's Lake is remarkably similar to zone 3 of McMaster Lake. The main discrepancy between M3 and Q3 is that the PAR at Queen's Lake is half to a third of what it is at McMaster Lake, and the CHAR at Queen's Lake is half of what it is at McMaster Lake.

Zone Q4: (*Betula*-*Pinus*-*Alnus* Zone): 15-0 cm (~3 820 BP-present)

Zone 4 of Queen's Lake is delineated by a decrease in *Picea mariana* (~12%) and an increase in *Pinus* (up to 22%). An increase in Ericaceae to ~3%; in *Myrica* to ~3% and in *Sphagnum* to ~4% also delimits Q4. *Betula* only increases slightly to levels of ~42%. Cyperaceae also increases, but only slightly, from <1% to ~1.5%. *Alnus crispa* and *Alnus incana* remain unchanged.

None of these changes are apparent in the PAR diagram, which depicts a marked decrease of all taxa in this zone. Zone 4 is marked by a low PAR (~100 grains/cm/year). CHAR falls to values of ~1*102 mm^2/cm^2/year. Algal gyttja was deposited in the bottom 3 cm of this zone; this was overlain with sandy organics. This sediment contained more inorganic material than the sediment in the previous zone.

Q4 is quite similar to M4. *Myrica* increases in Q4, but does not in increase in M4. Dramatic decreases in total PAR are evident at both lakes, but total PAR remains greater at McMaster Lake than Queen's Lake. Similarilly, CHAR decreases at both lakes, but continues to be less at Queen's Lake than at McMaster Lake.

4.3 Numerical Comparison of the Fossil Pollen with Modern Pollen Samples

The DCs calculated using SEDM to compare modern pollen assemblages to fossil pollen assemblages are provided on maps (figure 19 to 37). There is one map for each fossil pollen assemblage. Sites where modern pollen was collected are depicted on the maps. The value of the dissimilarity coeffìcent calculated for the comparison of the fossil pollen assemblage to a given modern pollen assemblages is indicated at the site where the modern pollen sample was collected. The result is that for a given fossil pollen sample there is a pictorial representation of the degree of similarity which exists between that fossil pollen assemblage and modern pollen assemblages from the forest, the forest-tundra and the tundra.

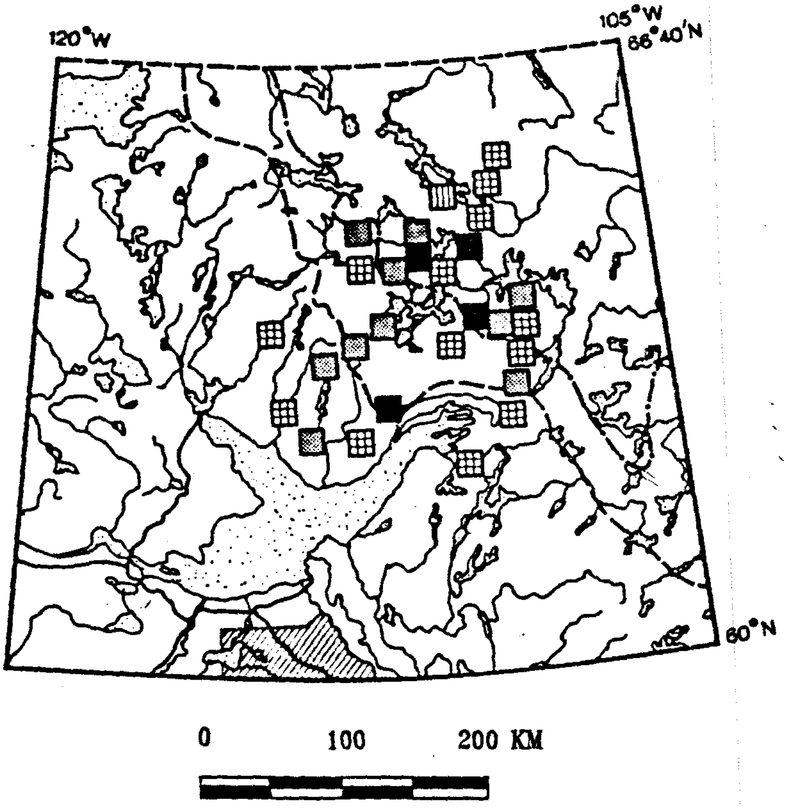
McMaster Lake

There are no modern analogues for the fossil pollen spectra deposited prior to ~5 250 BP. The modern pollen sample from the site furthest north of treeline bears the greatest similarity to the ~5 250 fossil pollen assemblage. There does not appear to be a meaningful pattern in the distribution of the modern pollen assemblages most similar to fossil pollen assemblages deposited between ~5 250 BP and ~3 690 BP. Fossil pollen samples from ~4 000 BP and ~3690 BP were only significantly similar to one modern pollen sample.

Figures 19-37: **Dissimilarity coefficent maps.** Twenty fossil pollen samples, nine from Queen's Lake and eleven from McMaster Lake, were compared to the twenty-eight modern pollen samples using dissimilarity coefficents. A study area map depicting the location of the modern pollen collection sites is provided for each fossil pollen sample. The value of the dissimilarity coefficent resulting from the comparison between the fossil pollen sample and the modern pollen sample is indicated on the map at the modern pollen site. A patterened scale is used to represent different dissimilarity coefficent values. It is important to note that prior to ~5 250 BP no modern analogues exist for the fossil pollen. From ~5 250 BP to ~5 000 BP fossil pollen assemblages are most like pollen assemblages from north of treeline. Fossil pollen assemblages from ~5 000 to ~3 500 BP are similar to those south of treeline. Following ~3 500 BP the fossil pollen assemblages are increasingly similar to tundra samples. Figures 19-28 are from McMaster Lake and figures 29-37 are from Queen's Lake.

McMASTER LAKE

0 B.P.



------ Tree line - - - Forest Tundra

Degree of Similarity (0 is the greatest similarity)

■ 0 - 3.9

▥ 6.0 - 6.9

▨ 4.0 - 4.9

▒ 7.0 - 7.9

▦ 5.0 - 5.9

▤ > 8.0

Figure 19

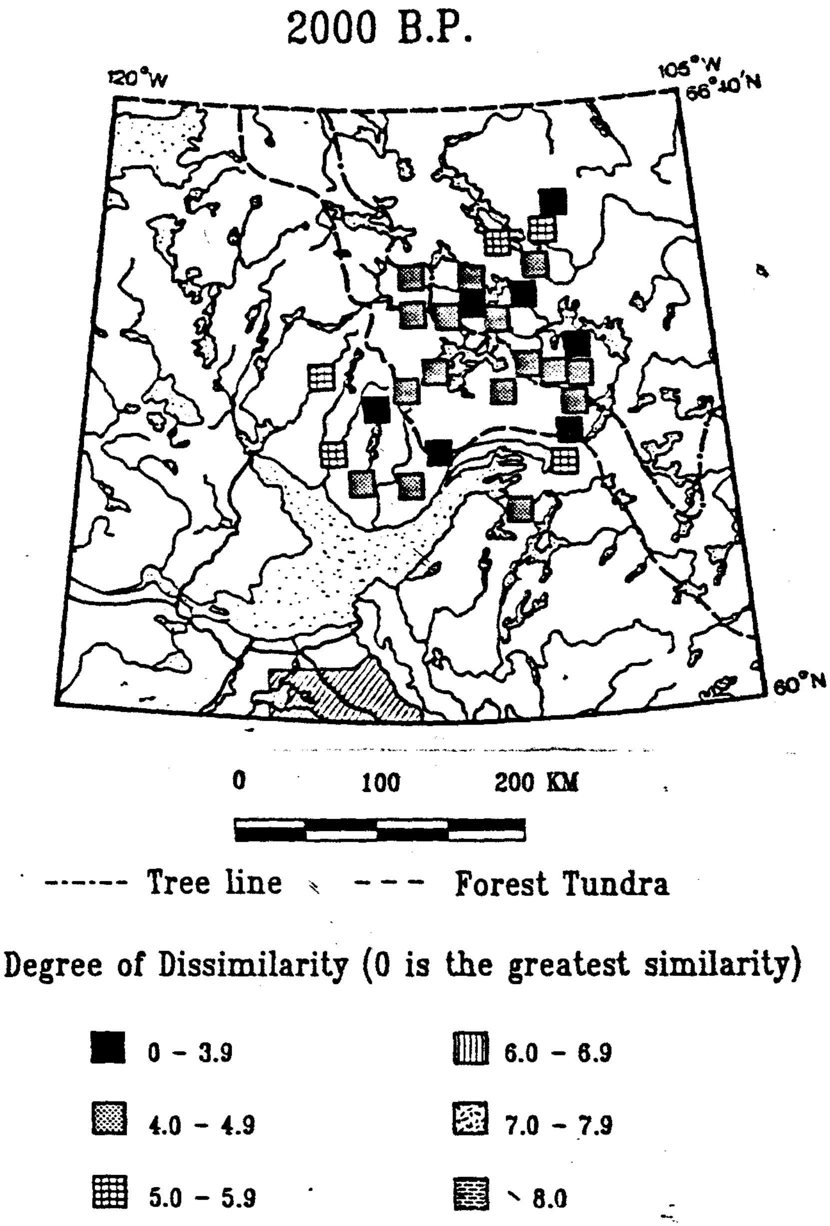
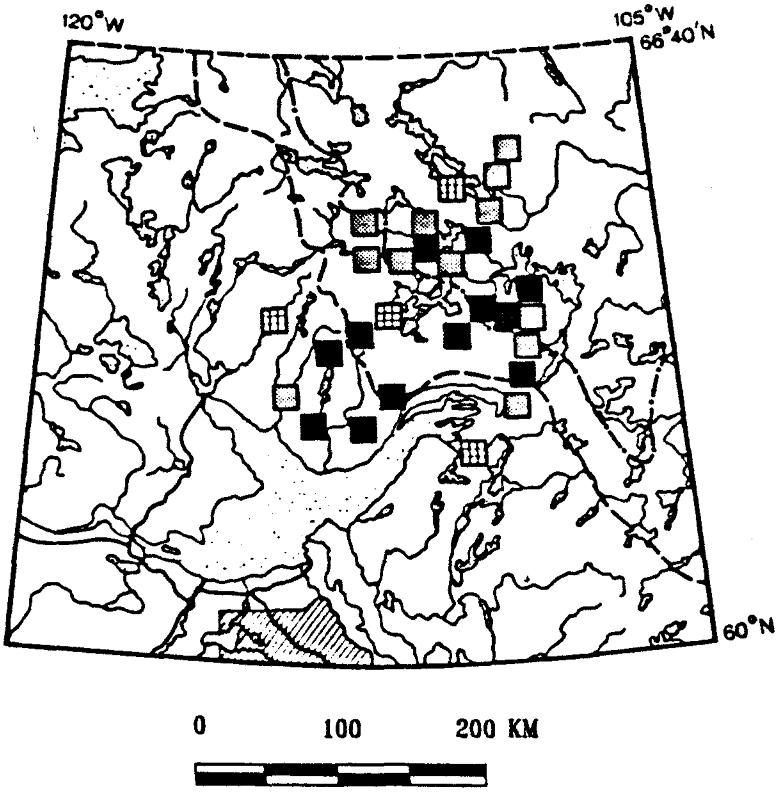

2000 B.P.
120°W
105°W
66°10'N
60°N
0
100
200 KM
------ Tree line
--- Forest Tundra
Degree of Dissimilarity (0 is the greatest similarity)
0 - 3.9
6.0 - 6.9
4.0 - 4.9
7.0 - 7.9
5.0 - 5.9
> 8.0

Figure 20

3000 B.P.



------ Tree line --- Forest Tundra

Degree of Similarity (0 is the greatest similarity)

■ 0 - 3.9
▥ 6.0 - 6.9
▒ 4.0 - 4.9
░ 7.0 - 7.9
▦ 5.0 - 5.9
▤ > 8.0

Figure 21

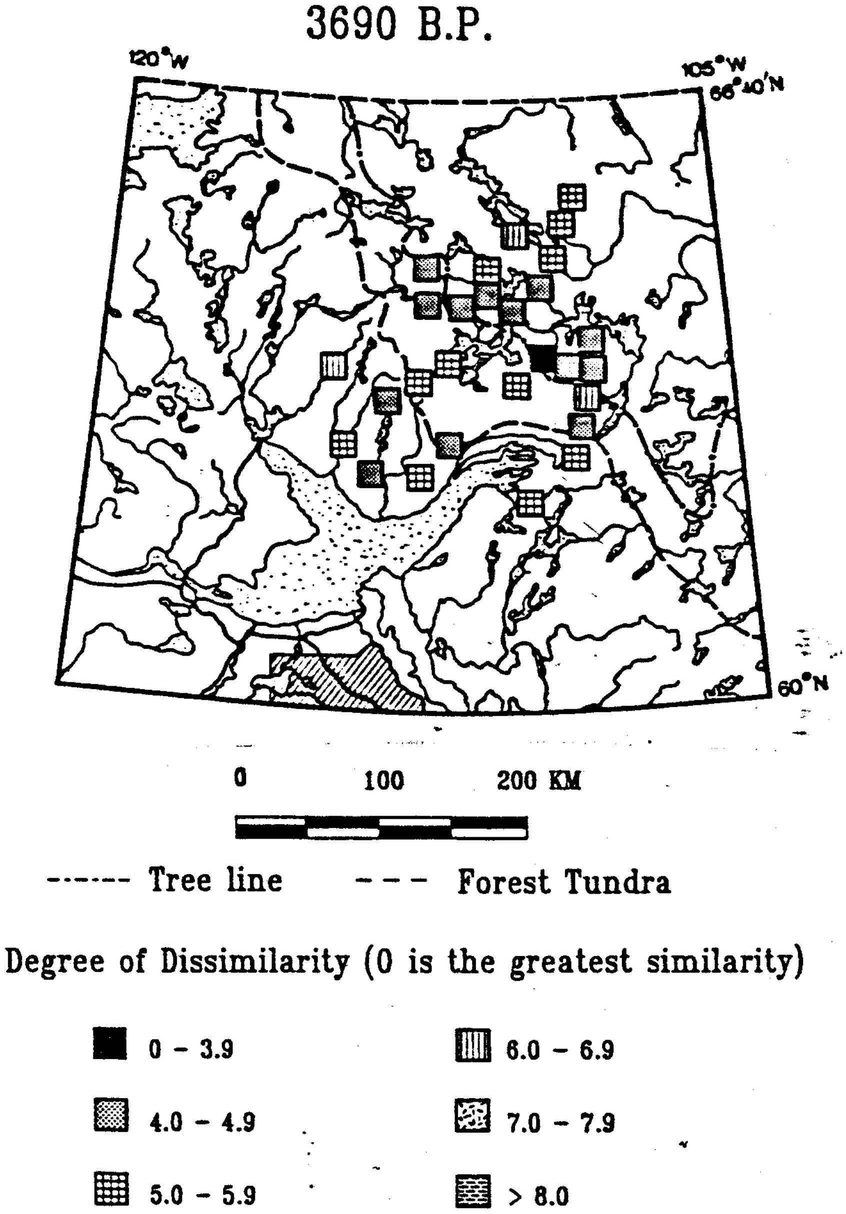

3690 B.P.
120°W
105°W
66°40'N
60°N
0
100
200 KM
------ Tree line
- - - Forest Tundra
Degree of Dissimilarity (0 is the greatest similarity)
■ 0 - 3.9
▒ 4.0 - 4.9
▦ 5.0 - 5.9
▥ 6.0 - 6.9
▨ 7.0 - 7.9
▤ > 8.0

Figure 22

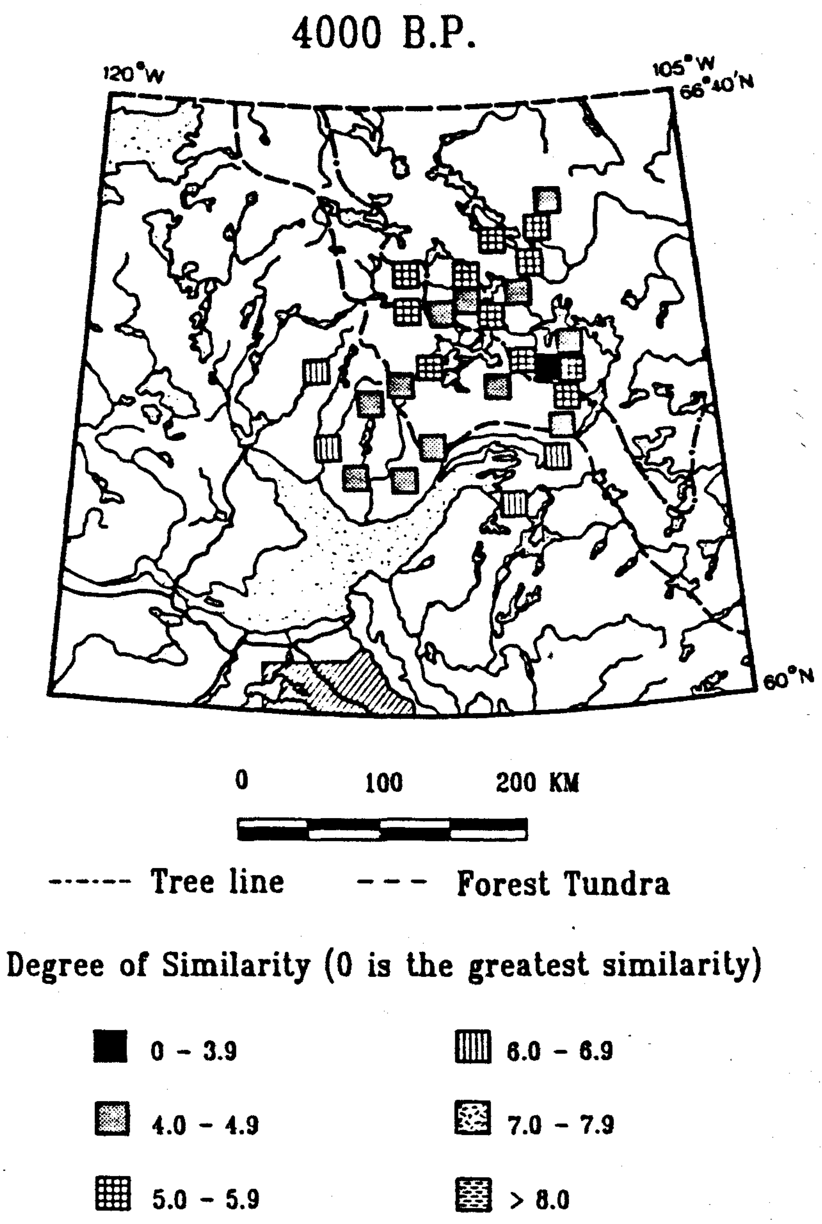

4000 B.P.
120°W
105°W
66°40'N
60°N
0
100
200 KM
------ Tree line
- - - Forest Tundra
Degree of Similarity (0 is the greatest similarity)
0 - 3.9
4.0 - 4.9
5.0 - 5.9
6.0 - 6.9
7.0 - 7.9
> 8.0

Figure 23

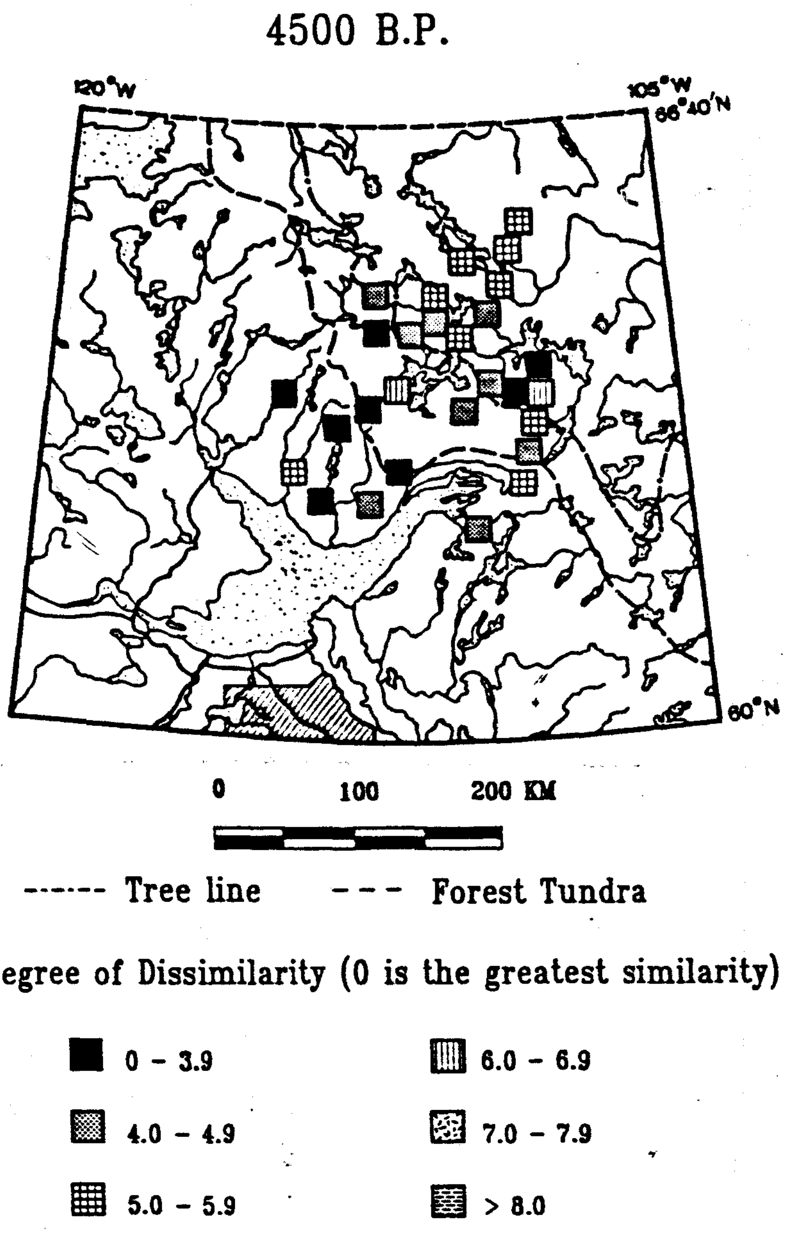

4500 B.P.

Figure 24

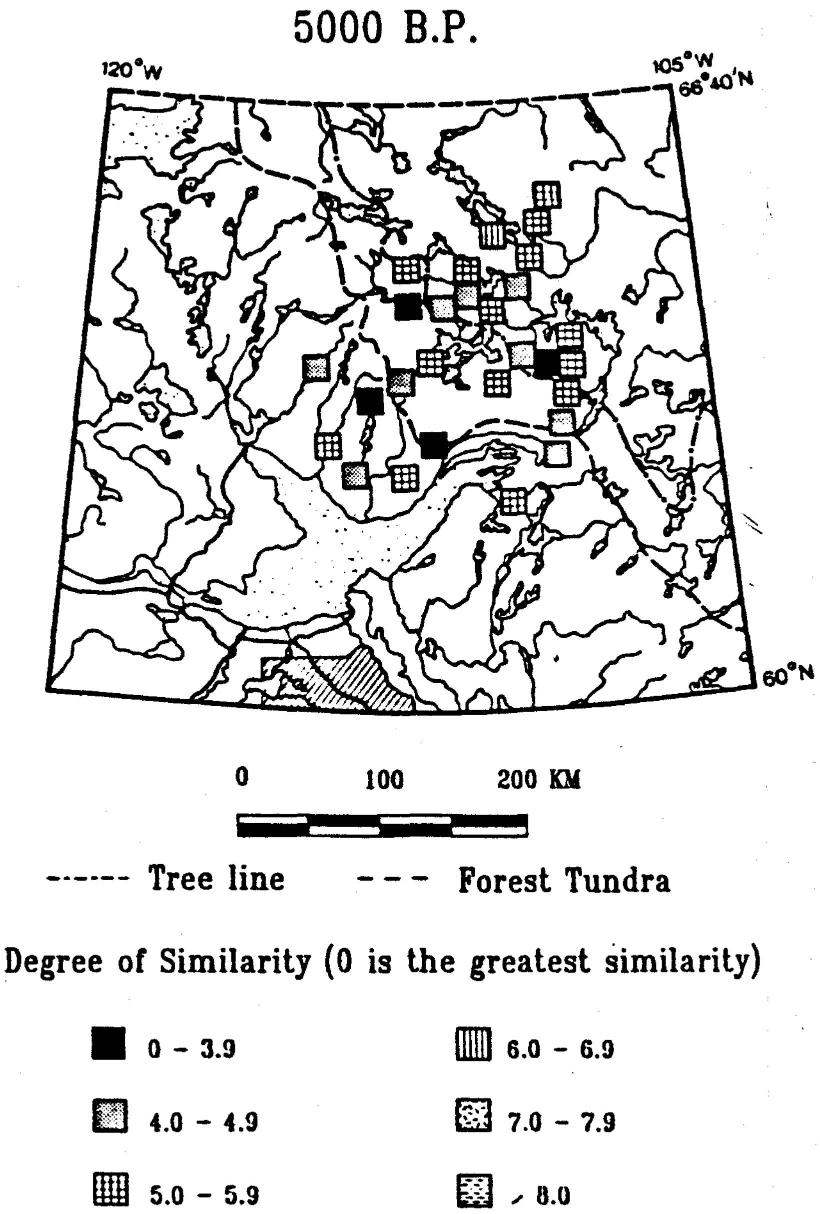

5000 B.P.
120°W
105°W
66°40'N
60°N
0
100
200 KM
------ Tree line
- - - Forest Tundra
Degree of Similarity (0 is the greatest similarity)
0 - 3.9
4.0 - 4.9
5.0 - 5.9
6.0 - 6.9
7.0 - 7.9
> 8.0

Figure 25

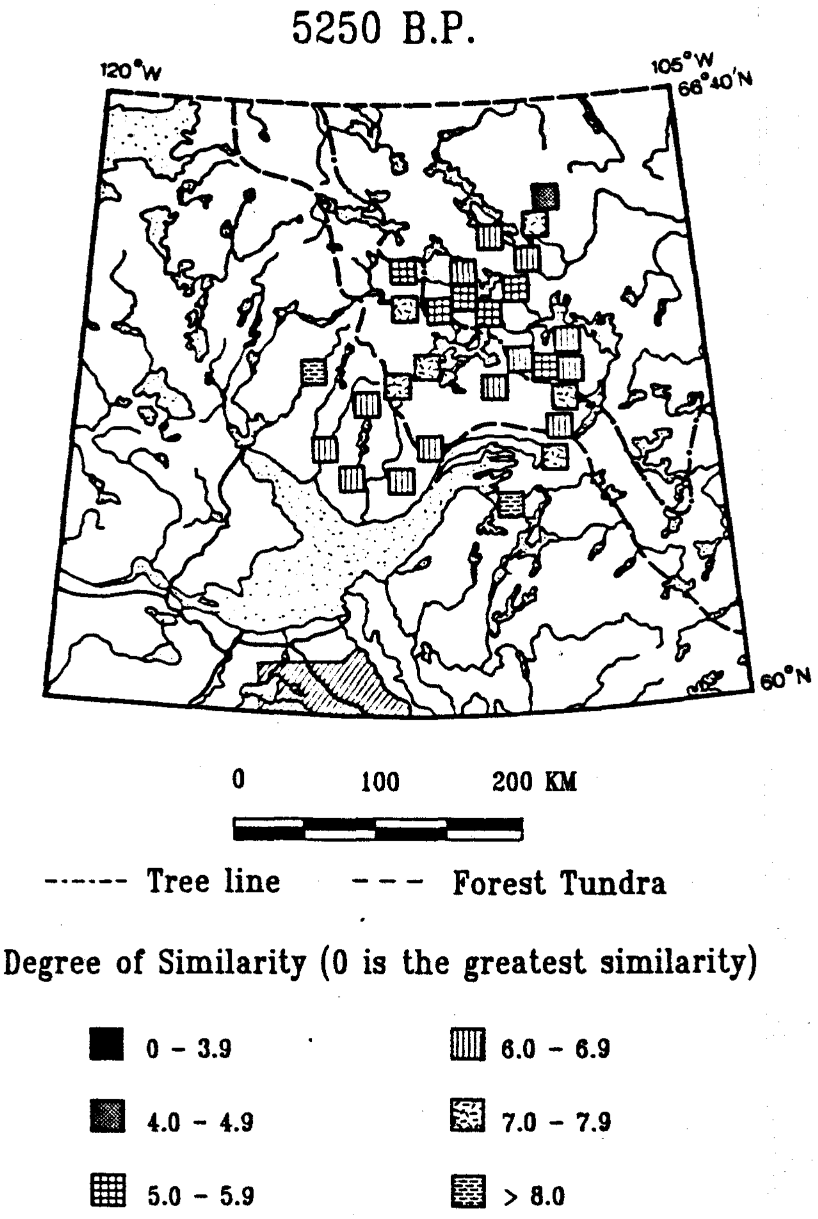

5250 B.P.
120°W
105°W
66°40'N
60°N
0
100
200 KM
------ Tree line
- - - Forest Tundra
Degree of Similarity (0 is the greatest similarity)
0 - 3.9
4.0 - 4.9
5.0 - 5.9
6.0 - 6.9
7.0 - 7.9
> 8.0

Figure 26

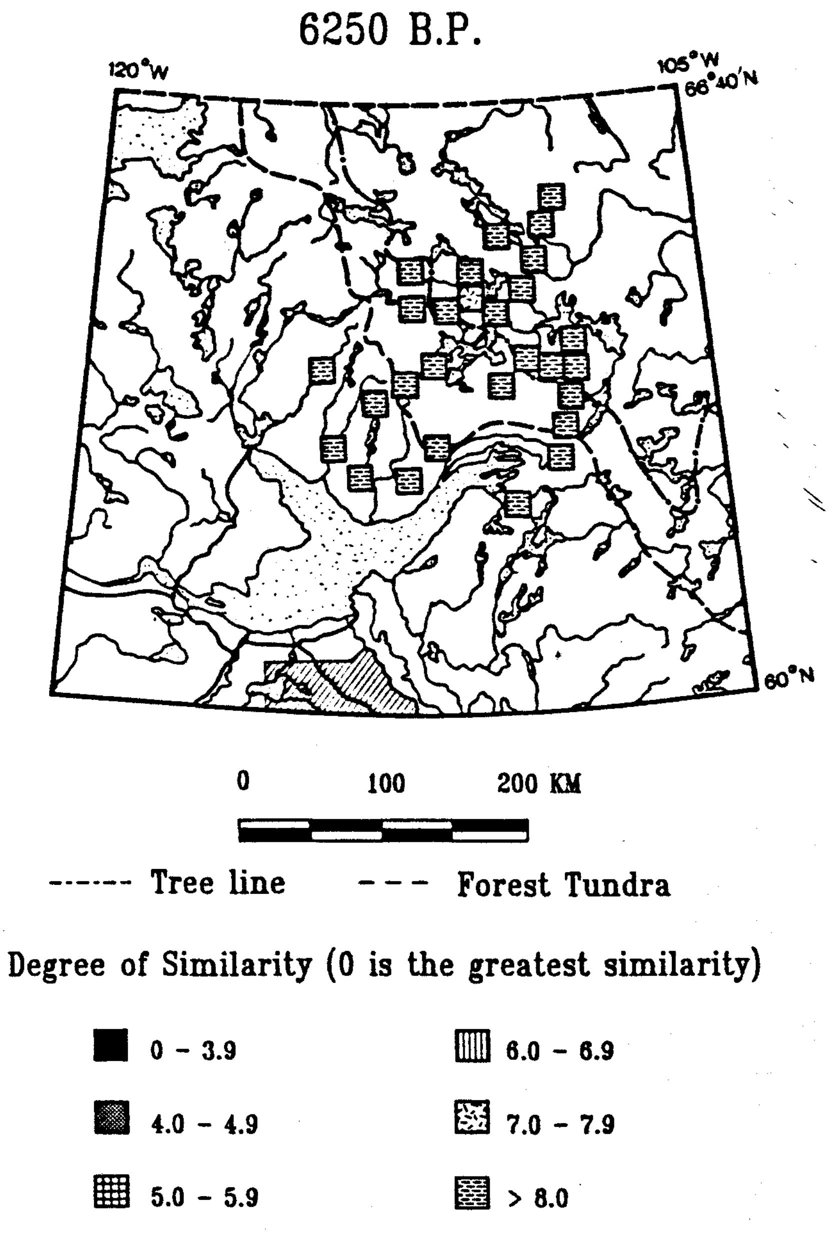

6250 B.P.
120°W
105°W
66°40'N
60°N
0
100
200 KM
------ Tree line
- - - Forest Tundra
Degree of Similarity (0 is the greatest similarity)
■ 0 - 3.9
▩ 4.0 - 4.9
▦ 5.0 - 5.9
▥ 6.0 - 6.9
▨ 7.0 - 7.9
▤ > 8.0

Figure 27

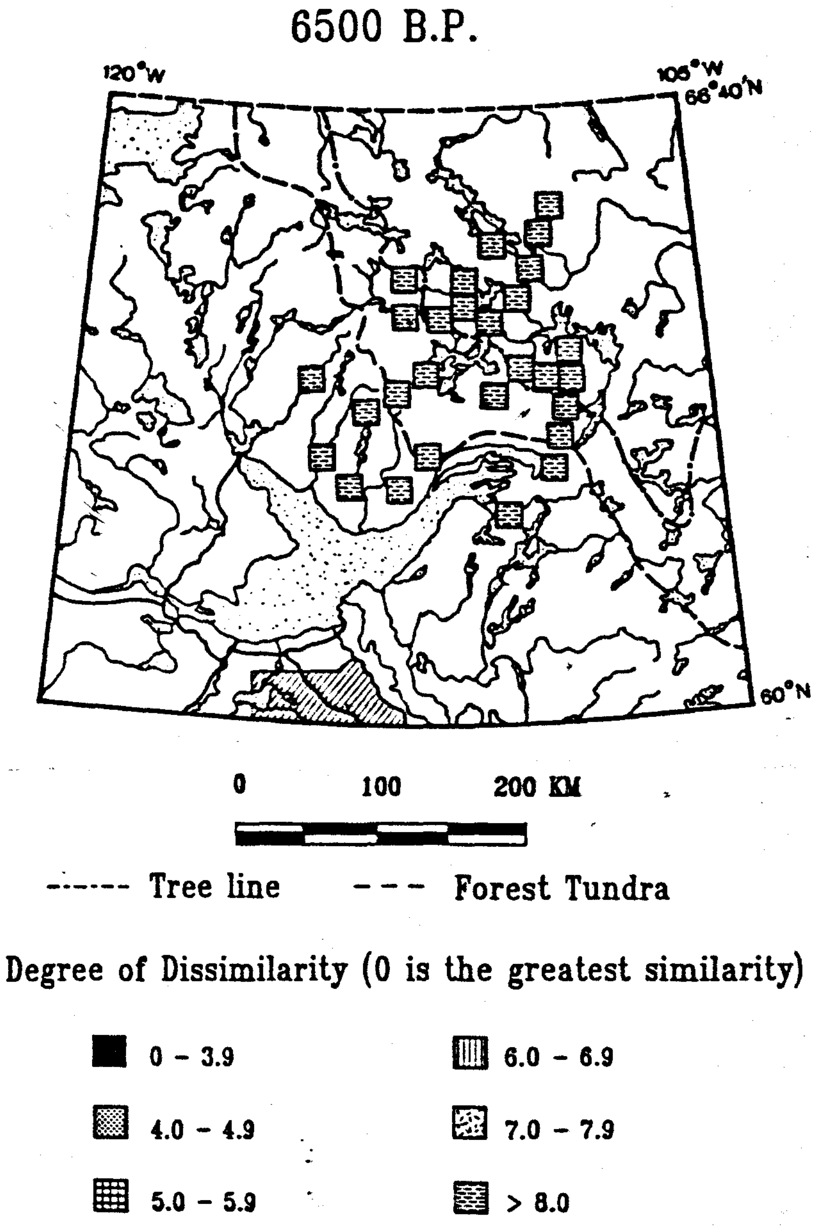
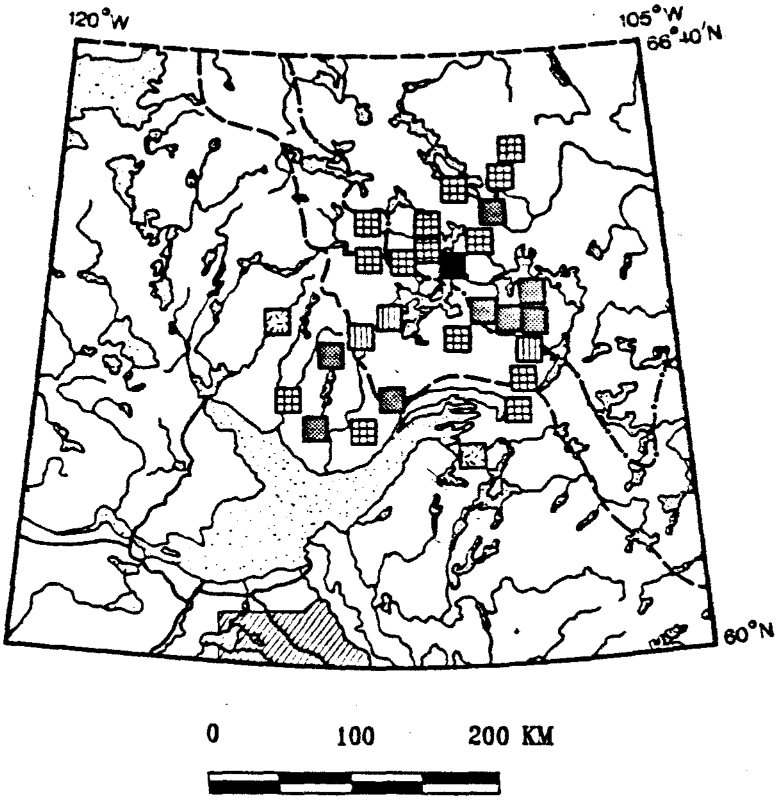

6500 B.P.
120°W
105°W
66°40'N
60°N
0
100
200 KM
------ Tree line
- - - Forest Tundra
Degree of Dissimilarity (0 is the greatest similarity)
■ 0 - 3.9
▩ 4.0 - 4.9
▦ 5.0 - 5.9
▥ 6.0 - 6.9
▨ 7.0 - 7.9
▤ > 8.0

Figure 28

QUEEN'S LAKE

0 B.P.



------ Tree line   - - - Forest Tundra

Degree of Similarity (0 is the greatest similarity)

■ 0 - 3.9	▥ 6.0 - 6.9
▩ 4.0 - 4.9	▒ 7.0 - 7.9
▦ 5.0 - 5.9	▤ > 8.0

Figure 29

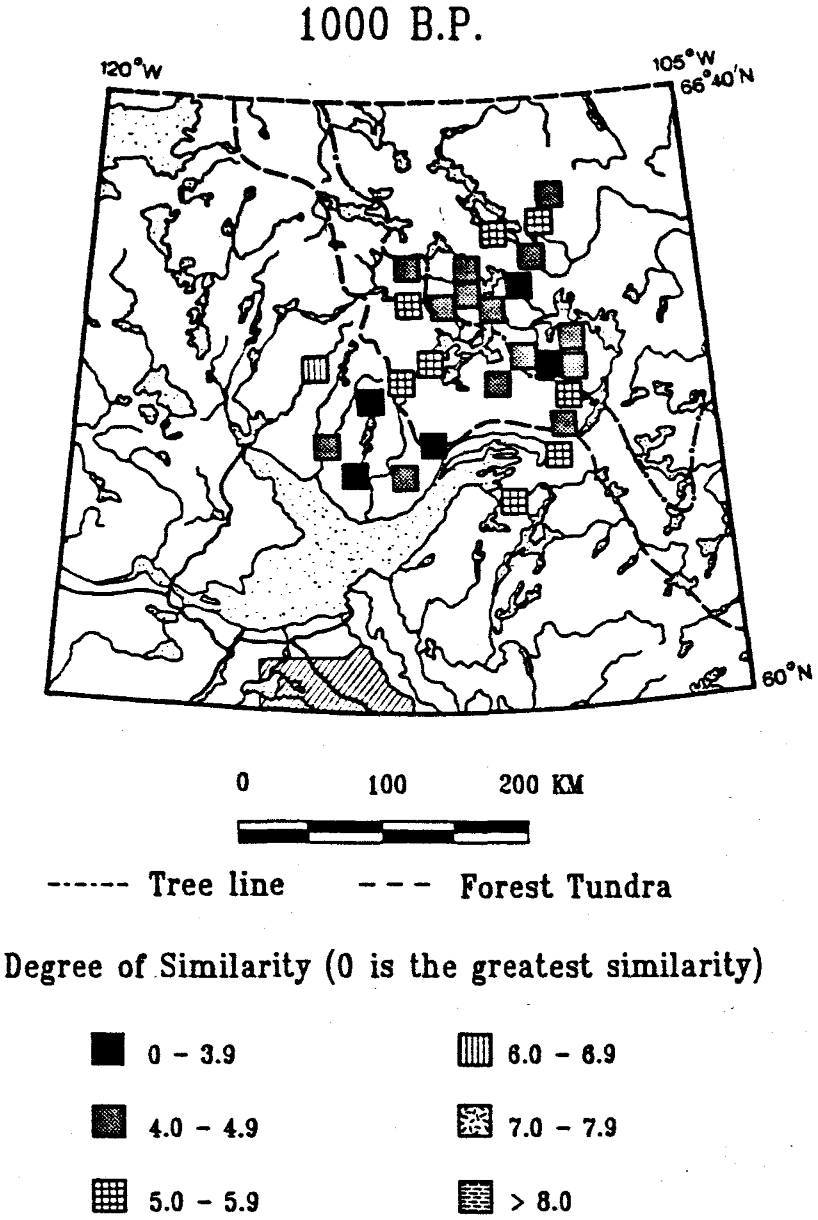
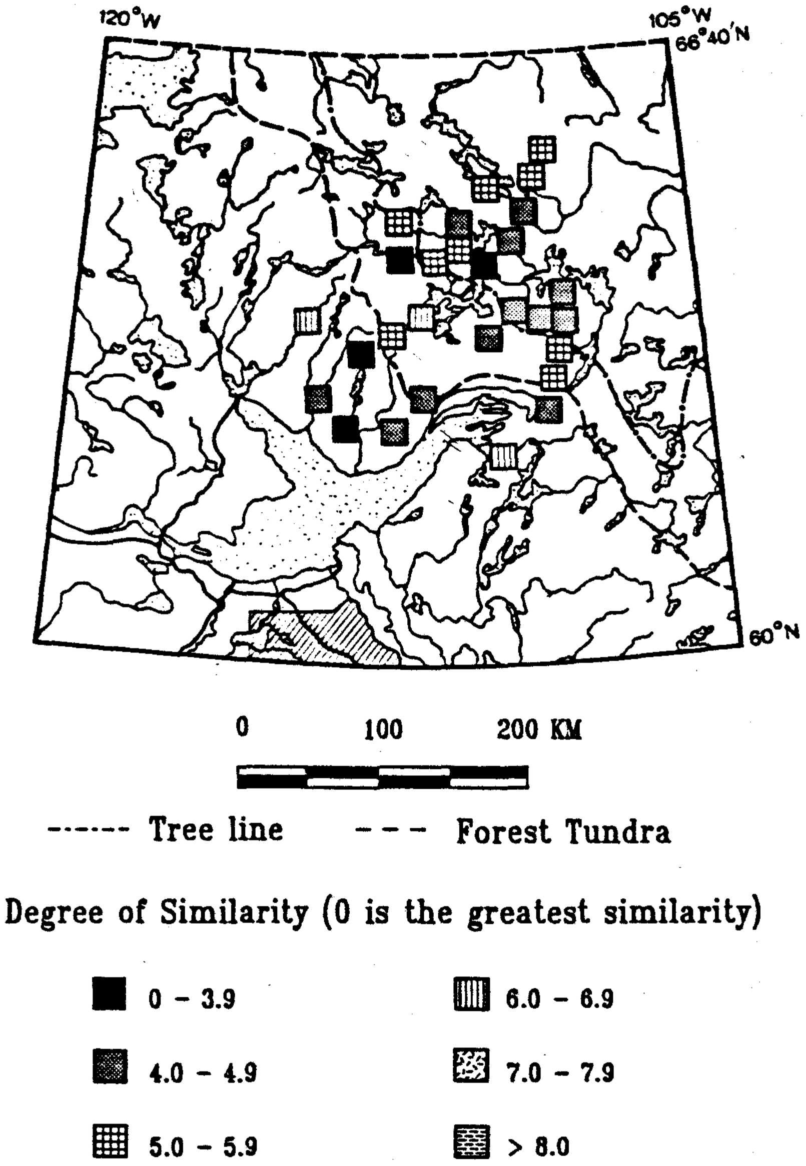

1000 B.P.
120°W
105°W
66°40'N
60°N
0
100
200 KM
------ Tree line
– – – Forest Tundra
Degree of Similarity (0 is the greatest similarity)
■ 0 - 3.9
▦ 4.0 - 4.9
▦ 5.0 - 5.9
▥ 6.0 - 6.9
▨ 7.0 - 7.9
▤ > 8.0

Figure 30



2500 B.P.

Figure 31

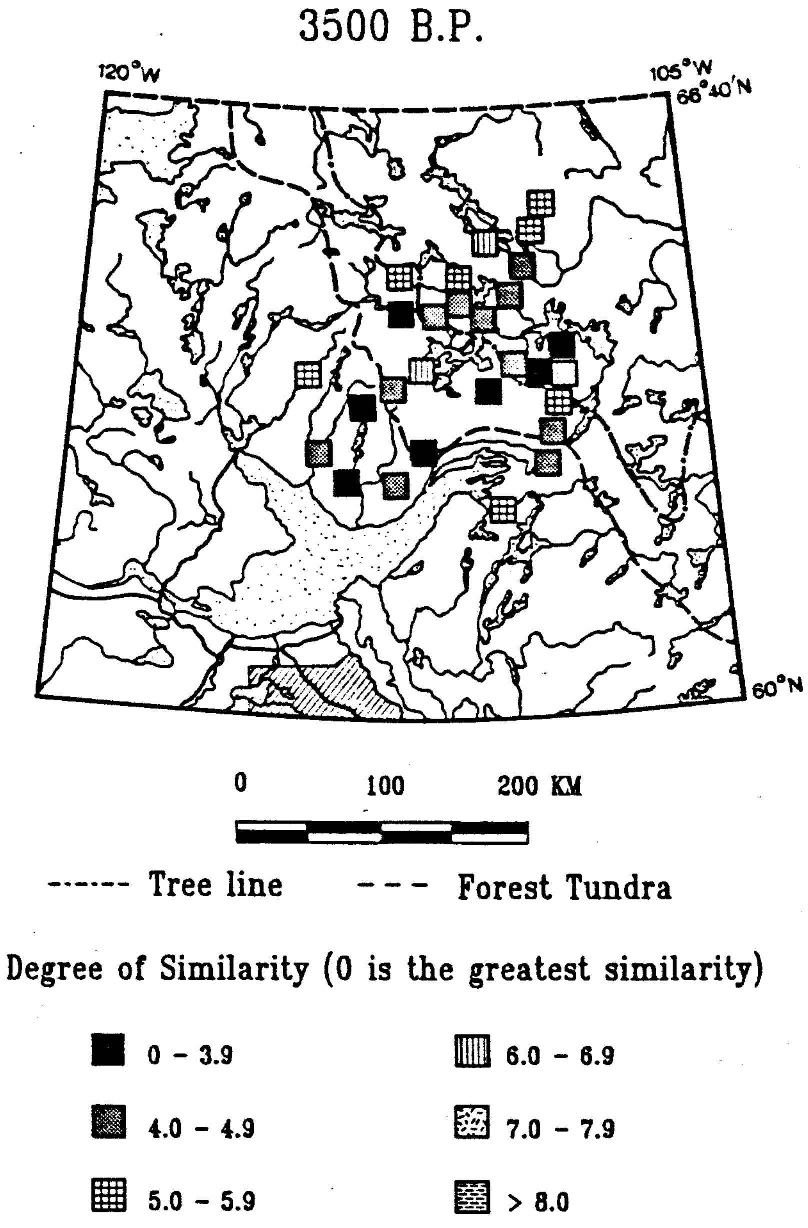
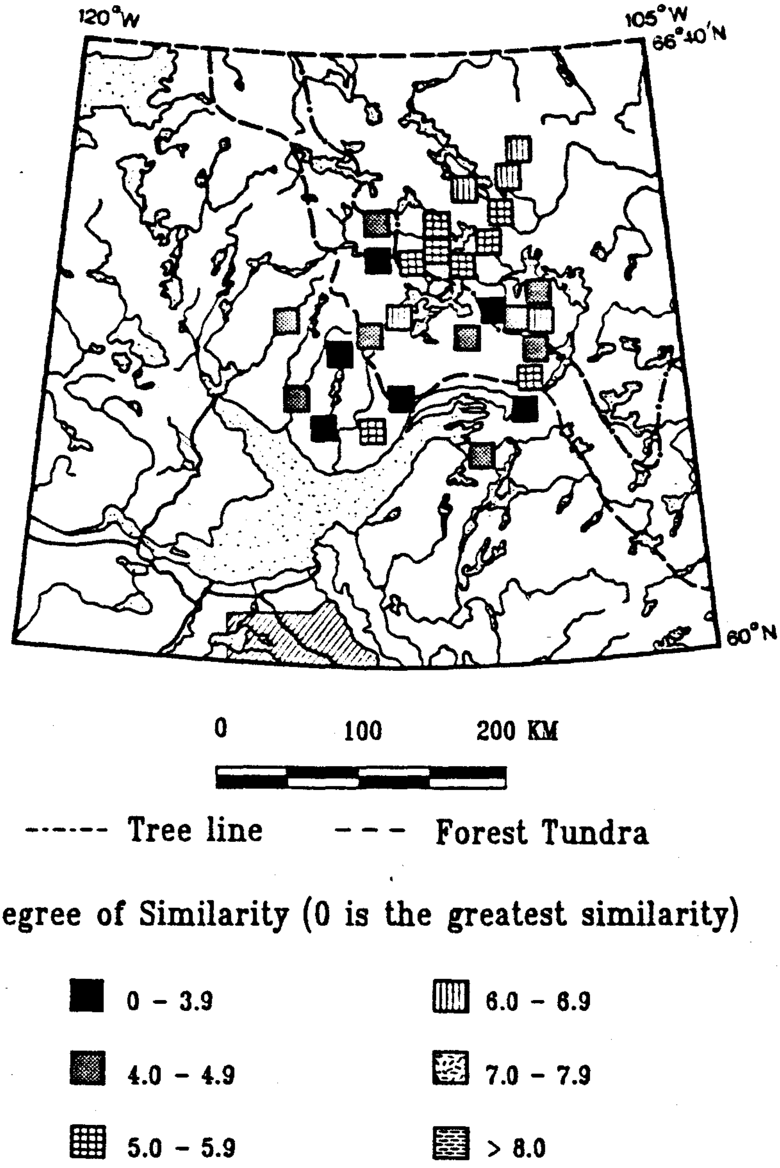

3500 B.P.
120°W
105°W
66°40'N
60°N
0
100
200 KM
------ Tree line
- - - Forest Tundra
Degree of Similarity (0 is the greatest similarity)
■ 0 - 3.9
▩ 4.0 - 4.9
▦ 5.0 - 5.9
▥ 6.0 - 6.9
▨ 7.0 - 7.9
▤ > 8.0

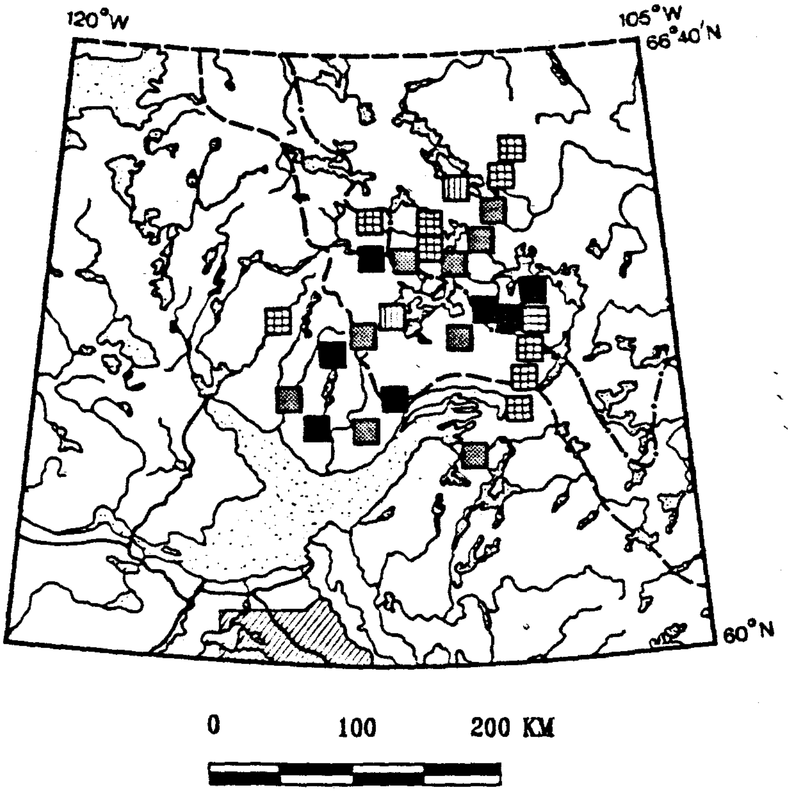
Figure 32



4000 B.P.

Figure 33

4500 B.P.



------ Tree line   - - - Forest Tundra

Degree of Similarity (0 is the greatest similarity)

■ 0 - 3.9	▥ 6.0 - 6.9
▩ 4.0 - 4.9	▨ 7.0 - 7.9
▦ 5.0 - 5.9	▤ > 8.0

Figure 34

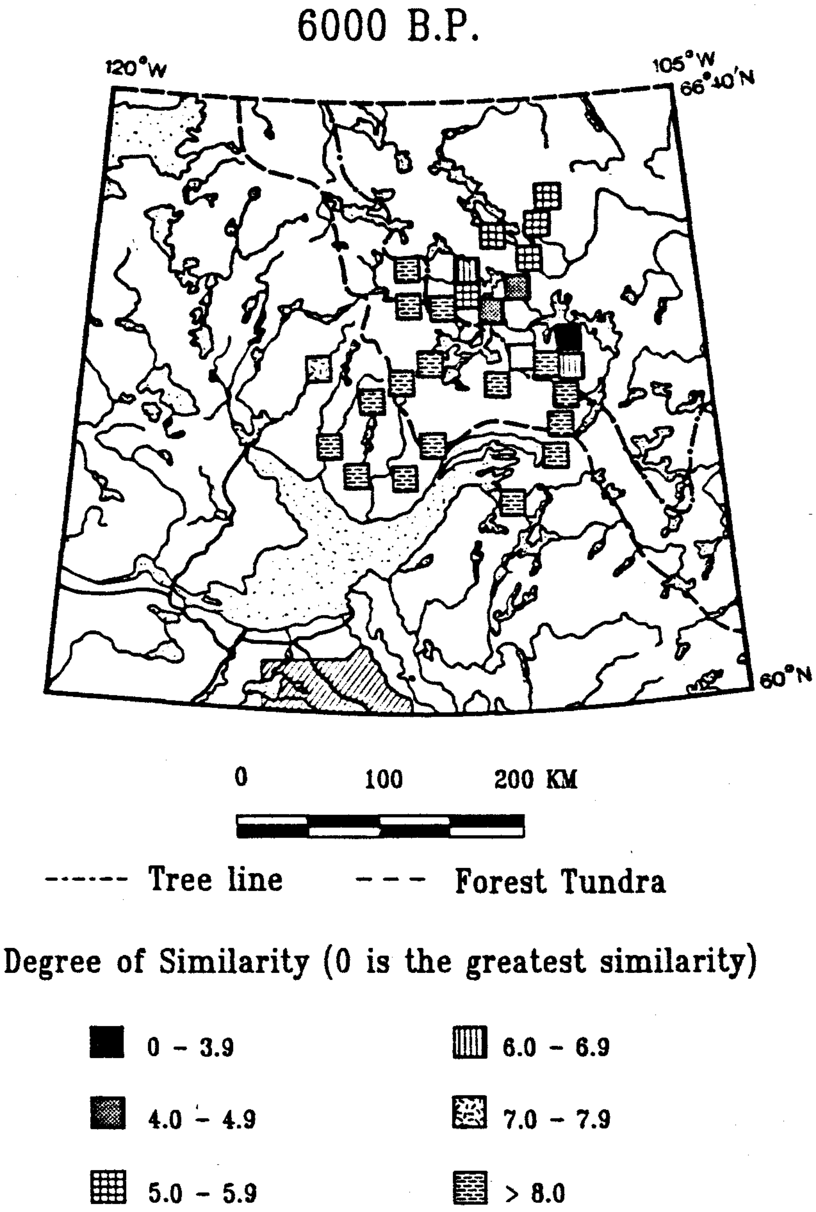

6000 B.P.
120°W
105°W
66°40'N
60°N
0
100
200 KM
------ Tree line
- - - Forest Tundra
Degree of Similarity (0 is the greatest similarity)
0 - 3.9
6.0 - 6.9
4.0 - 4.9
7.0 - 7.9
5.0 - 5.9
> 8.0

Figure 35

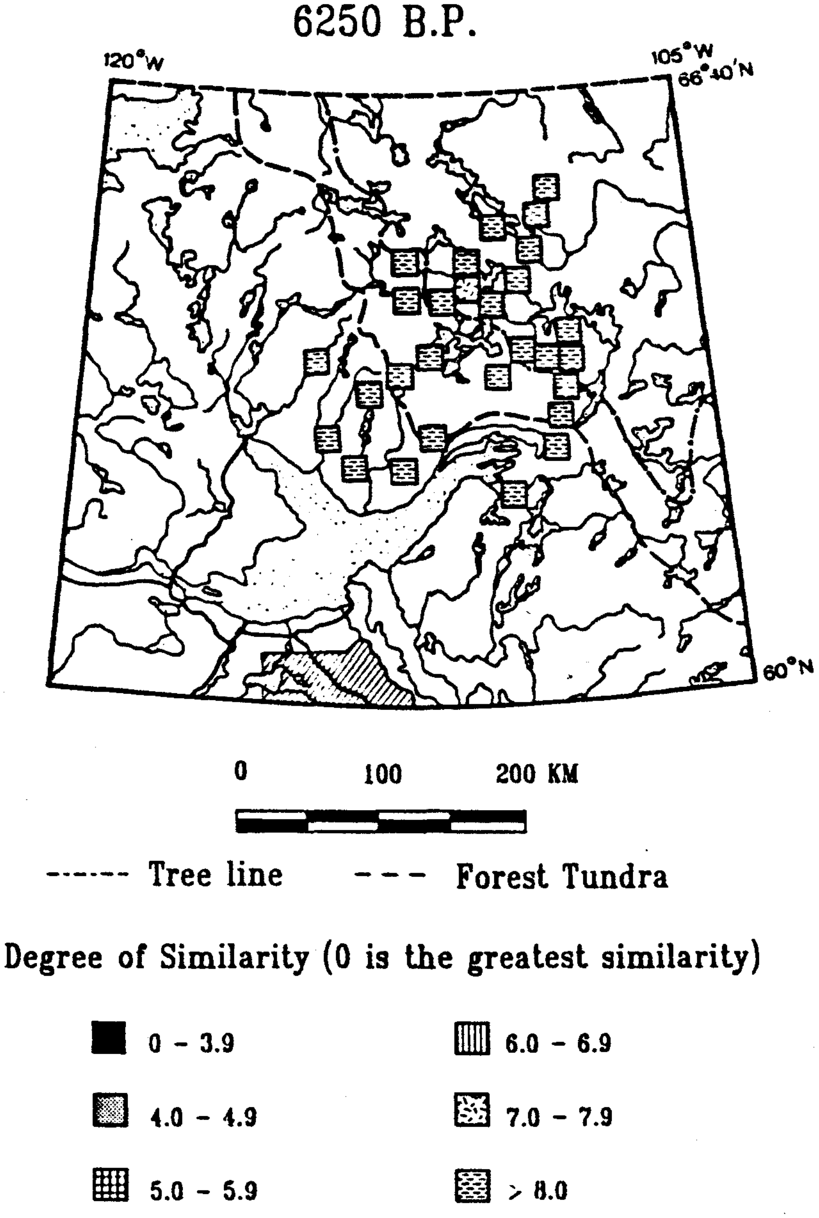

6250 B.P.
120°W
105°W
66°40'N
60°N
0
100
200 KM
------ Tree line
- - - Forest Tundra
Degree of Similarity (0 is the greatest similarity)
■ 0 - 3.9
▒ 4.0 - 4.9
▦ 5.0 - 5.9
▥ 6.0 - 6.9
▨ 7.0 - 7.9
▤ > 8.0

Figure 36

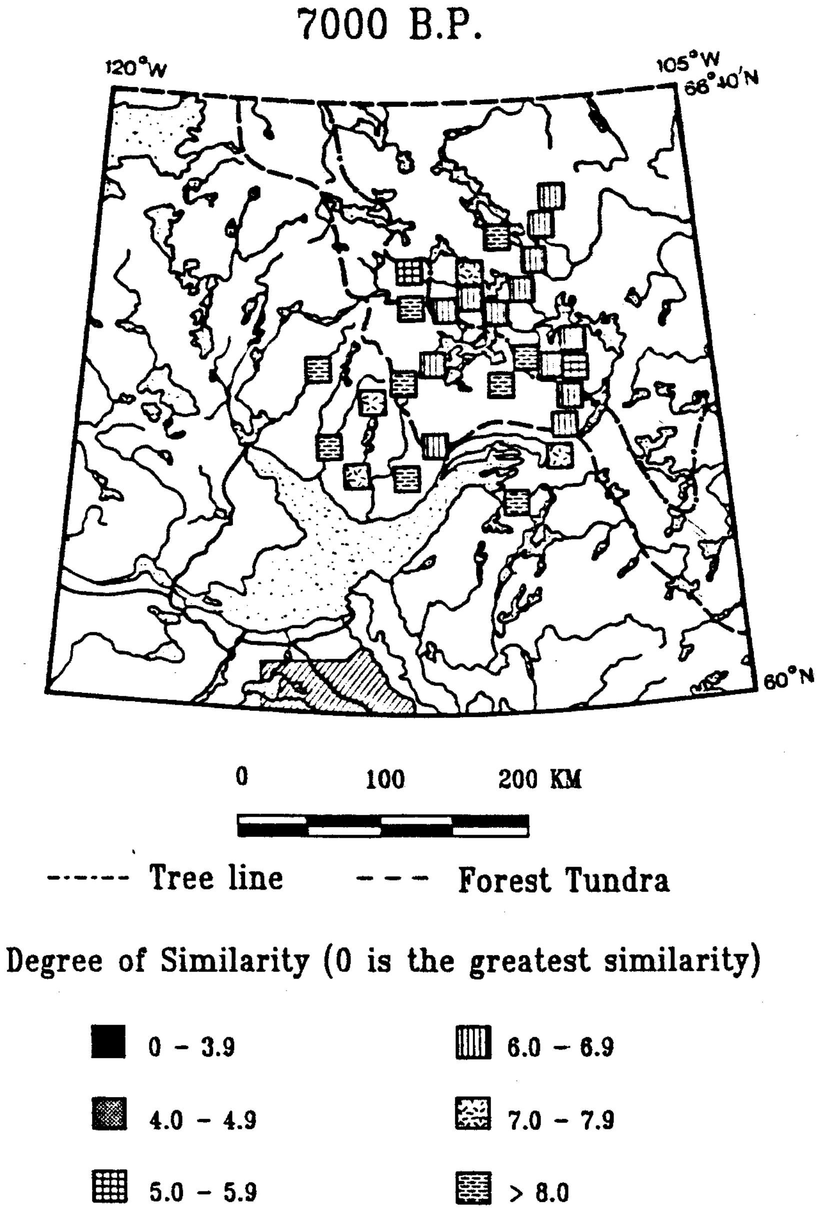

7000 B.P.
120°W
105°W
68°40'N
60°N
0
100
200 KM
------ Tree line
– – – Forest Tundra
Degree of Similarity (0 is the greatest similarity)
■ 0 - 3.9
▒ 4.0 - 4.9
▦ 5.0 - 5.9
▥ 6.0 - 6.9
▨ 7.0 - 7.9
▤ > 8.0

Figure 37

The fossil pollen assemblage from ~3 000 BP is most like modern pollen assemblages from sites south of treeline. By ~2 000 BP and continuing to the present the fossil pollen shares a greater similarity with sites north of the treeline.

Queen's Lake

There are no modern pollen assemblages similar to the fossil pollen assemblage from ~7 000 BP. There is only one modern pollen assemblge (in the tundra zone) which is similar to the fossil pollen spectrum deposited at ~6 000 BP. The fossil pollen assemblages from ~5 000 BP, ~4 500 BP, and ~4 000 BP are most similar to modern pollen assemblages from sites at and south of treeline. The number of modern pollen sites similar to the fossil pollen increases from ~5 000 BP to ~4 000 BP. The fossil pollen spectrum from ~2 500 BP is similar to four modern pollen samples representing all three vegetation zones. Comparison of the pollen assemblage from ~1 000 BP with those from the present reveals that this fossil pollen sample is most like modern pollen collected from tundra sites, especially those near treeline.

CHAPTER 5 VEGETATION RECONSTRUCTION

Four zones were identified from the fossil pollen records of Queen's and McMaster Lake:

i) *Betula*-Cyperaceae Zone;

ii) *Betula*-*Alnus* Zone;

iii) *Betula*-*Picea*-*Alnus* Zone; and

iv) *Betula*-*Pinus*-*Alnus* Zone.

These zones represent vegetational changes through time. Comparisons of fossil pollen with modern pollen analoques makes it possible to infer the past environment of some zones. The slight differences between the pollen record from McMaster Lake and from Queen's Lake will be examined to enhance the vegetation reconstruction.

5.1 The Fossil Pollen Record

The vegetation history represented by each of the four fossil pollen zones identified from the McMaster and Queen's Lake cores will be reconstructed based upon ^{14}C chronology, pollen percentages, PAR, CHAR and sediment characteristics.

Zone 1

The age of the basal zone differs between McMaster Lake and Queen's Lake. M1 begins at ~6 800 BP and extends to ~5 500 BP, while Q1 begins at ~7 400 BP and ends at ~6 800 BP. The cause of this discrepancy is related to the position of the *Alnus* zone boundary and will, therefore, be discussed in the succeeding section.

The dominant taxon present in the basal zone is *Betula*, probably *Betula glandulosa* (see discussion 4.1). *B. glandulosa* is the common species in the shrub tundra of Canada. The pollen percentage diagrams from both McMaster and Queen's Lake indicate that substantial amounts of *Betula* pollen were deposited throughout this period. *Betula* is known to produce relatively large amounts of pollen and is, therefore, often over-represented by pollen percentages (Ritchie, 1984). Yet, it has been estimated in similar studies of early Holocene vegetation that pollen percentages as high as those in this zone represent an abundance of *Betula* that is 4-6X as great as it is in modern tundra vegetation (Ritchie, 1977).

Similarily, Alnus is over-represented in the pollen record. In areas where Alnus is present, but not a significant component of the vegetation, it is an important component in the pollen record (Ritchie, 1984). All the modern pollen assemblages in this study include a significant proportion of Alnus. The nearly complete absence of this genus in the basal zones of the pollen records, as well as the high percentages of Betula pollen explains the lack of modern analoques for this zone.

Several taxa, including Cyperaceae, Artemisia, Cheno.-Am., and Rosaceae, reach maximum quantities in the basal zone of both cores. Although these taxa are common in modern tundra pollen assemblages each of these groups includes a large number of species which inhabit a broad range of habitats. The presence of Myrica, Sphagnum, and Ericaceae, all taxa which prefer wet, acidic areas, indicates the early development of 'boggy' areas, typical of the northern boreal forest and tundra.

Typha latifolia at the base of these cores is incongruous with the existence of a tundra environment since its modern range does not include areas north of treeline in western Canada. Ritchie (1984) used T. latifolia to indicate warmer climates in his palaeoenvironmental reconstruction of the far northwest of Canada. T. latifolia pollen has a maximum dispersal range of 1km (Krattinger, 1975) and the northern limit of its present-day distribution lies approximately 300km south of McMaster and Queen's Lake (Hulten, 1979). These two factors would suggest that the presence of _T. latifolia_ indicates a relatively warm environment. Explanations for the presence of _T. latifolia_ in what seems to have been an arctic environment will be discussed in 6.2.

Although, arboreal pollen is represented in the basal zone from both lakes it is in insignificant amounts and can be regarded as exotic.

The PAR diagram from McMaster Lake depicts a significant increase in _Betula_ between ~6 800 BP and ~6 250 BP, indicative of an increase in vegetation cover (Ritchie, 1984). _Betula_ PAR at Queen's Lake decreases, mirroring the total PAR which continues to decrease upward through the core. _Betula_ PAR does not correlate with the pollen frequency information or with evidence from the McMaster Lake core. The PAR of each taxon also reflects the general trends illustrated by the total PAR. Sedimentation rate decreases dramatically from the bottom to the top of the core. This implies that PAR is more influenced by changes in sedimentation rates than changes in the amount of pollen being deposited. The decrease in PAR is similar to that described from Mirror Lake, New Hampshire, which was concluded to be the result of sediment focussing at the bottom of the core (Davis and Ford, 1982). Sediment focussing is the concentration of sediment to the deepest part of the basin (Davis, 1968). Lehman (1975) showed that sediment accumulation decreased through time in frustrum and hyperboloid-shaped lakes. The lack of other evidence to support a decreasing PAR, as well as the fact that PAR of all taxa is directly related to the sedimentation rate, suggests that the PAR from Queen's Lake is obscured by sediment focussing.

Low PAR is indicative of meagre vegetation coverage. The lowest PAR at McMaster Lake occurs in zone 1. At Queen's Lake the greatest PAR occurs in this zone, and decreases continually to the top of the core. As already explained, this is a reflection of sediment focussing.

CHAR in tundra environments is relatively low as a result of fuel shortage and low fire frequency. The sparse tundra vegetation limits available fuel. In the modern tundra limited cyclonic activity, as a result of the southward position of the arctic front, restricts fire frequency (Johnson and Rowe, 1975; Johnson, 1979). Thus, low CHAR in M1 is consistent with tundra conditions. High charcoal influx in Q1 may be due to a high sedimentation rate resulting from sediment focussing.

Finally, zone 1 sediment is composed of a relatively small amount of organic matter. Sediment from modern tundra samples contains a comparable, although slightly greater, percentage of organics. Inorganic sediment deposited in modern tundra lakes is largely due to the sparse vegetation cover which results in the availability of considerable quantities of easily eroded material. Low lake productivity, typical of tundra environments, also contributes to a low organic to inorganic ratio (Wetzel, 1983).

The combination of all of these factors suggests a dwarf-birch tundra for zone 1 sediments similar to the early Holocene described for northwestern Canada (Ritchie, 1984; MacDonald, 1987a). However, the early presence of *Myrica*, Ericaceae, and *Sphagnum*, indicates the early development of boggy areas. Such development is not evident in the early Holocene pollen assemblages described from northwestern Canada (Ritchie, 1976; 1977; 1984; 1985; Ritchie and Hare, 1971; MacDonald, 1983; 1987; MacDonald and Ritchie, 1986; ; and Spear, 1983).

Zone 2

Q2 begins ~1 300 BP earlier than M2, although both are terminated at the same time (~5 000 BP). There are three possible explanations for this inconsistancy:

i) inaccurate radiocarbon dating;

ii) the arrival of *Alnus* at Queen's Lake predated its arrival at McMaster Lake; or

iii) exotic *Alnus* pollen was deposited earlier at Queen's Lake as a result of Queen's larger size.

Bulk sediment was used for dating at both sites (table 4). Accelerator dating techniques were used to obtain dates from the McMaster core, while conventional ^{14}C dating techniques were used to obtain dates from the Queen's core. Large amounts of sediment were necessary to obtain enough carbon for the regular ^{14}C dating process. This may have resulted in an erroneous date. If, the dates are assumed to be correct, the possiblity that Alnus arrived earlier at Queen's Lake than at McMaster Lake can be considered. The two lakes, however, are only 2km apart so it seems unlikely that Alnus established itself at Queen's Lake, but was unable to expand to McMaster Lake. Finally, because Queen's Lake is significantly larger than McMaster Lake, it should include a larger component of exotic pollen (Jacobson and Bradshaw, 1981). If Alnus increased at a location some distance away, there would be an increase in exotic Alnus which might only be reflected in the Queen's Lake record. A rise in Alnus in the McMaster Lake record might not have occurred until Alnus was inhabiting areas proximal to the lake. Therefore, it might appear in the pollen record that Alnus arrived earlier at Queen's Lake than at McMaster Lake when, in fact, the earlier rise in Alnus was only the result of Queen's Lake's propensity to reflect changes in exotic pollen.

Although there is a chronological discrepancy between the the two lakes regarding the onset of the *Alnus* zone, the vegetation represented by these zones appears nearly identical. The continuation of a tundra type vegetation is supported by the similarity of these fossil pollen assemblages to modern pollen assemblages collected from sites north of treeline. Both sites depict a dramatic increase in *Alnus*, mainly *Alnus crispa*, but also *Alnus incana*. Although this increase is significant in both the pollen percentage and PAR records, the fact that *Alnus* is an efficient pollen producer may mean that the actual increase is not as dramatic (Ritchie, 1984).

None of the other taxa, including *Betula*, show significant changes from zone 1 to zone 2. Cyperaceae does decrease in the pollen frequency diagrams, but it appears that this is only a reflection of its relative importance as it does not decrease in the PAR diagrams. There is also a slight increase in *Sphagnum* at Queen's Lake, and of Rosaceae at McMaster Lake. Since these changes are only recorded at one of the two lakes it is likely that they represent local vegetational changes.

Besides being similar to the *Betula* zone in terms of pollen assemblages, the *Alnus* zone resembles the *Betula* zone in terms of PAR, CHAR, and sediment type. The pollen records from both lakes indicate slight increases in PAR, although the increase at Queen's Lake only occurs in the early half. This increase may be reflecting the increase in vegetation coverage as a result of the increase in Alnus. It is worth noting that PAR in this zone and in all succeeding zones is significantly larger at McMaster Lake than Queen's Lake. This should be anticipated since Queen's Lake is 4X the size of McMaster Lake. More pollen is collected per unit area in smaller lakes than larger ones (Pennington, 1973). The sediments deposited during this interval continued to contain high proportions of inorganics suggesting that open, unvegetated sites prone to erosion continued to contribute clastic sediment to the lakes and/or lake productivity remained low..

The change in CHAR from zone 1 to zone 2 is small. One might expect that the increase in woody plants would increase the availability of fuel. However, if tundra conditions were maintained there would not be an accompanying increase in fire frequency, and thus no change in charcoal influx (Johnson, 1979).

Since few differences exist between the Alnus zone and the Betula zone, it would seem that there were only slight modifications in the vegetation. The increase in vegetation cover as a result of the increase in Alnus is the distinguishing feature.

Zone Three

A dramatic and abrupt increase in Picea mariana at ~5 000 BP in both cores delineates this zone in the pollen percentage and PAR diagrams from Queen's and McMaster Lake. This zone persists until ~3 820 BP and ~3 680 BP respectively. It is notable that the increase is recorded in the PAR diagrams from Queen's Lake where sediment focussing has generally masked changes in pollen concentrations. This suggests that the increase in pollen from Picea mariana was of sufficent magnitude to be detected despite the effects of sediment focussing. Unlike, Picea mariana, Picea glauca does not increase. This is consistent with modern treeline vegetation, as described in the Yukon (Ritchie, 1984), where Picea mariana is the dominant tree species.

Another arboreal species which increases significantly in the Picea zone is Pinus. Again, this increase is apparent in all pollen diagrams. However, unlike Picea mariana the quantity of Pinus pollen continues to increase to the upper portion of zone 4. No Pinus trees exist at present near either of the study sites. Therefore, the increase in Pinus must be the result of an increase in exotic Pinus pollen input reflecting population changes to the south. Pinus produces large amounts of easily transported pollen and therefore often comprises a significant proportion of the pollen sum deposited at lakes where it is not present (MacDonald and Ritchie, 1986).

With the expansion of Picea mariana it would follow that taxa such as Alnus and Betula would decrease as a result of the reduction of open areas. However, at McMaster

Lake a decrease in Alnus and Betula is only recorded in the pollen percentage diagram and not in the PAR diagram suggesting that, although the relative importance of Alnus and Betula has decreased , it continues to maintain its population. This implies that open areas persisted within the forest or that populations decreased but pollen production of individual plants increased as a result, for example, of an ameliorated climate.

The components of the vegetation clearly indicate a forest vegetation and several other factors provide further support for this hypothesis. PAR at Queen's Lake continues to decrease in this zone as a result of sediment focussing, but at McMaster Lake it increases markedly, implying an increase in pollen production. Similar to PAR, the CHAR continues to decrease at Queen's Lake, but at McMaster it increases. It follows that available fuel would increase with the existence of a forest vegetation. Picea mariana, as a result of its abundance of low branches, its ability to layer, and a common lichen covering, is an excellent fuel (Viereck, 1983).

The sediment deposited at this time is more organic-rich suggesting the colonization by vegetation of previously open sites and a decrease in clastics transported to the lake. In addition lake productivity may have increased. The establishment of Picea mariana interspersed with shrub dominated open areas, is clearly documented by the evidence presented above. The similarity of the fossil pollen assemblages to the modern pollen assemblages south of treeline, and especially those within the continuous forest provides, further confirmation of a forest or perhaps a forest-tundra vegetation existing during this period (figure 21-24 and 31-33).

Zone Four

The modern tundra zone for both lakes begins at almost the same time; ~3 680 BP at McMaster Lake and ~3 820 BP at Queen's Lake. There is a second date, ~3 690 BP, from McMaster Lake which is stratigraphically above the first date, ~3 680 BP. There is no evidence to support sediment mixing, so it likely represents a slight dating error. Five samples were originally submitted for dating. Two of these samples were destroyed in an explosion during processing. Two more samples were submitted a year later. One of these second samples (10 cm) was the ~3 690 BP date (TO-766). It is possible that some contamination occurred from the time of the original sampling to the time of the second sampling.

The onset of this zone is marked by a sharp decrease in <u>Picea</u> <u>mariana</u>. This indicates the rapid disappearance of the forest vegetation. A rapid increase in <u>Pinus</u> also defines the fourth zone. As previously discussed, this increase is the result of exotic pollen. <u>Betula</u> is the dominant taxon. Alnus, Myrica Ericaceae and Sphagnum are also present in this zone.

It is difficult to gain much information regarding the pollen record during this time because of distortion as a result of sediment focussing. In zone 4, from McMaster Lake and Queen's Lake, the PAR of all taxa diminishes markedly. During this time PAR is directly related to the sedimentation rate. This PAR decrease may be due to sediment focussing away from the portion of the lake bottom that these cores were removed from. In addition a decrease in PAR is often noted in the top few tens of centimetres of lake sediment cores (eg. MacDonald, 1987a)

Further evidence for the re-establishment of a tundra environment can be found in the CHAR record. At both sites CHAR decreases in zone 4. The decrease in sedimentation rate is partially responsible for this. However, it would follow that a return to tundra from forest would decrease available fuel and, perhaps, reduce forest fire frequency. This would lead to a decrease in charcoal influx. It is notable that there is a distinctive peak in the charcoal record from McMaster Lake at ~3 680 BP. Nichols (1975) reports synchronous, large CHARs from a number of pollen diagrams from sites east of this area at ~3 500 BP. It suggests that a number of widespread fires occurred during this period and that this peak represents such an event. However, it is not represented in the charcoal record from Queen's Lake.

LOI results reveal a decrease in the organic content of the sediment, indicating an increase in watershed erosion and/or a decrease in productivity.

Despite the influence of sediment focussing all evidence clearly indicates that a tundra vegetation, similar to that found at the study sites today, existed from the onset of this zone. As expected, comparisons of the fossil pollen assemblages with modern assemblages indicates a high degree of similarity between this zone and tundra samples.

CHAPTER 6 DISCUSSION

6.1 Introduction

The previous section established the major changes in vegetation which occurred at the study sites following the last period of deglaciation. The following discussion will compare the history of post-glacial vegetation change north of Yellowknife with the results of similar studies elsewhere in Canada and attempt to isolate the factors such as climate (precipitation and temperature), edaphic and hydrological conditions, fire, and biological controls that caused vegetation change. Hypotheses regarding the environmental controls on the vegetation of each zone will be derived by considering the modern ecology of the important taxa of that zone. Figure 2 depicts the generalized pollen stratigraphy for western Canada (Tuktoyaktuk Peninsula and the Mackenzie Delta); central Canada (Keewatin District); and eastern Canada (Labrador-Ungava). For the purpose of this thesis, detailed analysis will be limited to a comparison with pollen diagrams from western Canada. Examination of pollen diagrams from central and eastern Canada will be brief because of interpretative problems and separation by immense geographical distances.

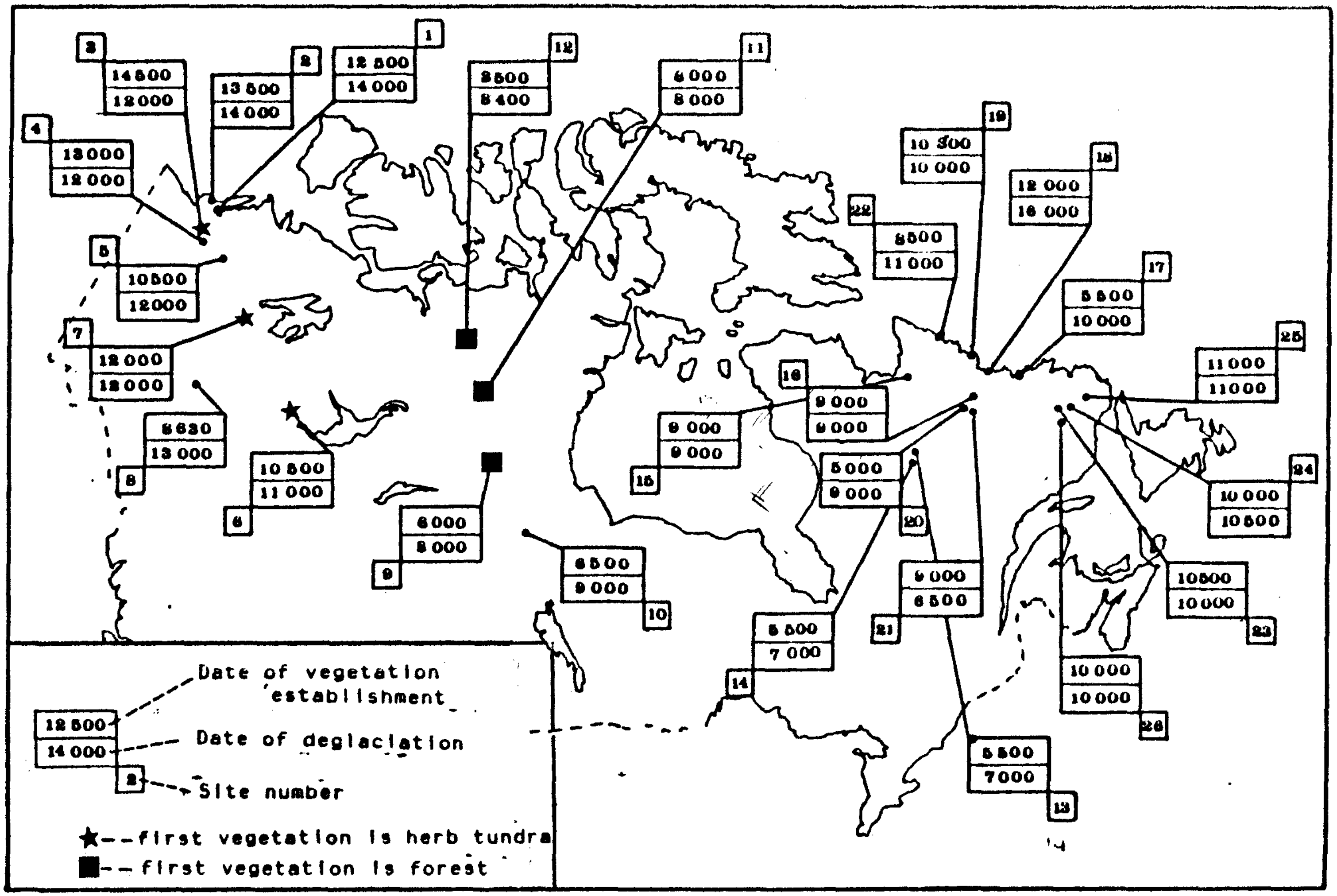
6.2 Zone 1

This zone represents a tundra environment dominated by shrub Betula and characterized by the presence of boggy areas. It is roughly similar to Betula shrub tundras from early Holocene pollen zones described in western (Ritchie, 1976; 1977; 1984; 1985; Ritchie and Hare, 1971; MacDonald and Ritchie, 1986; MacDonald, 1983; 1987a; Spear,1983) and eastern (Short and Nichols, 1977; Lamb, 1980; 1984; 1985; Richard et al., 1982; Engstrom and Hansen, 1985) Canada. No early tundra zone has been described in pollen analysis from central Canada (Nichols, 1967a; 1967b; 1970; 1975; Kay, 1979).

Although a Betula tundra vegetation is represented in pollen records from western and eastern Canada, the timing of this zone varies in each area (figure 2). In western Canada the dwarf -birch shrub tundra zone began between ~14 000 BP and ~10 000 BP and extended until ~9 500 BP (Ritchie, 1976; 1977; 1984; 1985; Ritchie and Hare, 1971; MacDonald, 1983; 1987a; MacDonald and Ritchie, 1986 and Spear, 1983). A shrub tundra existed in the eastern arctic from as early as ~9 000 BP until ~4 500 BP (Short and Nichols, 1977; Lamb, 1980; 1984; Richard et al., 1982; Engstrom and Hansen, 1985). The Betula tundra zone recorded at McMaster Lake and Queen's Lake persisted from ~ 7 200 BP to ~6 000 BP. The chronological differences in the occurance of the Betula zones appears related to differences in the timing of deglaciation. A map (figure 38) depicts the sites of several pollen diagrams from near the treeline. Each site is marked with two dates; one represents the time of deglaciation (Dyke and Prest, 1987), and the other represents the earliest indication of vegetation, in most cases a shrub tundra. At some sites in western Canada the Betula tundra zone is preceded by a herb tundra zone. At these sites the date indicating the earliest vegetation represents the onset of a herb tundra (these sites are indicated on the map by a star, figure 38). In central Canada the earliest vegetation is marked by the establishment of forest. These sites are denoted by a square. It is obvious that initial vegetation follows closely behind deglaciation. This is supported by Major and Crocker (1955) who found that vegetation was able to establish itself immediately following the disappearance of glacial ice.

As well as differences in the timing of the Betula tundra zones from across Canada, differences in the complement of the minor taxa are found in each region. The most striking distinction is the early establishment of Myrica, Ericaceae, and Sphagnum at McMaster Lake and Queen's Lake. These taxa are not known in the Betula tundra records from sites in western Canada (Cwynar, 1982; Ritchie, 1976; 1977; 1984; 1985; Ritchie and Hare, 1971; MacDonald,1983; 1987a; MacDonald and Ritchie, 1986; Spear, 1983). These

Figure 38: **Deglaciation map.** This map illustrates the location of the pollen records used to construct generalized pollen diagrams from western, central and eastern Canada. Two dates are provided at each site: the bottom date is the time of deglaciation (from maps by Dyke and Prest, 1987) and the top relates to the first presence of vegetation following deglaciation. Note that these two dates are almost always similar. The sites used include: 1)Tuktoyaktuk (Ritchie and Hare, 1971); 2)Sleet Lake (Ritchie, 1984); 3)Twin Tamarack (Ritchie, 1984); 4)M-Lake (Ritchie, 1984); 5)Sweet Little Lake (Ritchie, 1984); 6)Lac Demain (MacDonald, 1987a); 7)Lac Meleze (MacDonald, 1987a); 8)Nalta Bog (MacDonald, 1983); 9)Ennadai Lake (Nichols, 1967a;b); 10)Lynn Lake (Nichols, 1967a;b) 11)Long Lake (Kay,1979); 12)Pelly Lake (Nichols, 1970); 13) Daumont Site (Richard et al., 1982); 14)Delorme II (Richard et al., 1982); 15)Pyramid Lake (Short and Nichols, 1977); 16)Kogaluk Plateau (Short and Nichols, 1977); 17)Hopedale Pond (Short and Nichols, 1977); 18)Nain Pond (Short and Nichols, 1977); 19)Ubliik Pond (Short and Nichols, 1977); 20)Track Pond (Short and nichols, 1977); 21)Gravel Ridge (Lamb, 1985); 22)Hebron Lake (Lamb, 1984); 23)Eagle Lake (Lamb, 1980); 24)Paradise Lake (Lamb, 198?); 25)Lake Hope Simpson (Engstrom and Hansen, 1985); 26)Moraine Lake (Engstrom and Hansen, 1985).



1
12 500
14 000
2
13 500
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3
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11 000
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11 000
23
10500
10 000
24
10 000
10 500
25
11000
11000
26
10 000
10 000
12 500
14 000
2
Date of vegetation establishment
Date of deglaciation
Site number
★ - - first vegetation is herb tundra
■ - - first vegetation is forest

three taxa are indicative of bog development and prefer acidic, moist areas. The crystalline granite-gneiss bedrock as well as the poorly developed drainage of the Canadian Shield would produce such an area. In western Canada the freshly exposed, calcareous rocks would have resulted in better drainage and higher pH soils limiting bog development.

The presence of Typha latifolia at the base of the Betula zone also distinguishes this zone from the tundra zone described in western Canada. As was explained in 5.1, T. latifolia has been used as an indicator of climatic conditions suitable to support boreal forest (Ritchie, 1984). Thus, its presence in a tundra zone is anomolous. However, there are a number of plausible explanations for its presence in the Betula tundra. First, the possibility of contamination must be considered. This seems unlikely since T. latifolia is only found in the lower portions of the core, and not in any of those above.

A second possibility is that T. latifolia is exotic. Krattinger's (1975) results, however, indicate that pollen from this species is not transported further than 1km. It is possible that the pollen could have been transported long distances by birds. Savile (1956) showed that seeds of Lemna and Spurodela, both water plants, are carried in the wings of water birds. Perhaps it is possible for pollen to be transported this way, although the possibility of this seems remote.

A third suggestion is that favourable climatic conditions allowed the establishment of *T. latifolia* at the site during the *Betula* tundra zone while the development of forest was delayed by a factor such as migration lag. The proximal establishment of both *Picea glauca* and *Picea mariana* as early as ≈8 500 BP (Lac Demain, see MacDonald, 1987a), however, refutes migration lag as a mechanism to retard the establishment of a more productive vegetation.

Lastly, the early occurrence of *T. latifolia* may have been a response to the existance of a mineral rich substrate. *T. latifolia* prefers minerotrophic sites. The abundance of minerotrophic lake bottom substrates following deglaciation of the study area would provide such conditions favorable for the settlement of *T. latifolia*. Although often used as a palaeoclimatic indicator the presence of *T. latifolia* at the base of the cores from McMaster Lake and Queen's Lake can not be attributed directly to climate.

The *Betula* tundra zone described from McMaster Lake and Queen's Lake is quite similar to the dwarf-birch shrub tundra described in western Canada and to the shrub tundra in eastern Canada. Chronological differences in the establishment of tundra vegetation are related to the time of deglaciation. The presence of different taxa in the study area compared to western Canada can be attributed to substrate differences. A moist, acidic environment allowed for the early development of Ericaceae, *Myrica*, and *Sphagnum*, while minerotrophic conditions may be responsible for the early presence of *T. latifolia*.

6.3 Zone Two

The vegetation which inhabited Queen's Lake and McMaster Lake during the *Betula* tundra zone changes little in the *Alnus* zone. The only significant difference is the dramatic increase in the importance of *Alnus*, both *Alnus crispa* and *Alnus incana*.

Most postglacial pollen records from northern treeline sites include an increase in *Alnus*. The uppermost pollen zone of sites in northwestern Canada is delineated by an increase in *Alnus* at 6 000 BP. In eastern Canada, *Alnus* increases significantly towards the end of the shrub tundra zone at ~6 000-~5 000 BP. In fact there is a synchronous increase in *Alnus* at ~6 000 BP (between ~5 000 and ~6 800 BP) in every pollen record described from treeline sites from across Canada (table 5). One inconsistency with this is Pelly Lake (Nichols, 1970). The basal date on this core, however, is only ~3 360 BP which follows the onset of the *Alnus* zone. Reasons discussed to explain the *Alnus* rise have varied significantly.

In western Canada the *Alnus* rise followed the retreat of the treeline at ~6 000 BP (Ritchie, 1976; 1977; 1984; 1985; Ritchie and Hare, 1971; MacDonald, 1987a; MacDonald and Ritchie, 1986; Spear, 1983). Therefore the increase in *Alnus*, which prefers open areas, was attributed to the opening of spruce forests as a result of fire (Ritchie, 1985). MacDonald (1987a) suggested that the *Alnus*

Table 5: **The timing of the _Alnus_ expansion.** This chart provides the details of _Alnus_ expansions from sites across Canada. Notice that almost all the pollen records indicate an expansion of _Alnus_ between ~~6 800 BP and ~5 000 BP.

REFERENCE	SITE	ONSET (BP)	DECLINE (BP)	MAXIMUM %
WESTERN CANADA				
Ritchie & Hare, 1971	Tuktoyaktuk, NWT	5 440	3 630	70
Ritchie, 1984	Sleet Lake, NWT	6 600	4 200	60
Ritchie, 1984	Twin Tamarack, NWT	5 400	present	45
Ritchie, 1984	M-Lake, NWT	6 800	present	50
Ritchie, 1984	Sweet Little Lake, NWT	5 100	present	50
MacDonald, 1987a	Lac Demain, NWT	6 000	present	10
MacDonald, 1987a	Lac Meleze, NWT	6 000	present	15
MacDonald, 1983	Nalta Bog, NWT	4 000	present	15
CENTRAL CANADA				
Nichols, 1967a; b	Ennadai Lake, NWT	5 780	2 670	30
Nichols, 1967a; b	Lynn Lake, Man.	6 530	5 600	40
Kay, 1979	Long Lake, NWT	4 000	present	80
Nichols, 1970	Pelly Lake, NWT	3 360	present	20
EASTERN CANADA				
Richard et.al., 1982	Daumont Site, Labrador	5 490	4 480	45
Richard et.al., 1982	Delorme Il., Labrador	6 320	4 700	20
Short & Nichols, 1977	Pyramid Lake, Labrador	6 000	4 000	40
Short & Nichols, 1977	Kogaluk Plateau, Labrador	6 500	present	40
Short & Nichols, 1977	Hopedale Pond, Labrador	5 000	4 000	70
Short & Nichols, 1977	Nain Pond, Labrador	6 550	5 500	50
Short & Nichols, 1977	Ublik Pond, Labrador	6 500	4 500	40
Short & Nichols, 1977	Track Pond, Labrador	5 000	1 600	50
Lamb, 1985	Gravel Ridge, Labrador	6 470	5 525	50
Lamb, 1984	Hebron Lake, Labrador	5 600	present	45
Lamb, 1980	Eagle Lake, Labrador	6 500	5 000	60
Lamb, 1980	Paradise Lake, Labrador	6 200	6 000	30
Engstrom & Hansen,	Lake Hope Simpson,	10 000	8 000	20

expansion could have been facilitated by an increase in organic soils coincident with an increase in moisture.

In eastern Canada *Alnus* becomes important following and coincident with the establishment of a *Betula* dominated shrub tundra. Short and Nichols (1977) conclude that an ameliorating climate (both warmer and wetter) resulted in the replacement of tundra by shrub tundra although they do not provide an exclusive reason for the significant increase in *Alnus*. Lamb (1980) disputes Short and Nichols' (1977) hypothesis and suggests a successional model similar to that described by Crocker and Major (1955). Richard et al. (1982) indicate that the early establishment of *Alnus* in central Labrador is related to its ability to fix nitrogen through a symbiotic relationship with *Frankia* *actinomycete*. Nitrogen has been recognized as a limiting factor in vegetation distribution in the arctic (Russell, 1940; Haag, 1974). Therefore *Alnus*' ability to fix nitrogen would be expected to give it a competitive advantage in areas which have recently been deglaciated. However, evidence also exists for the accumulation of nitrogen in the absence of macroscopic vegetation (Crocker and Major, 1955), contradicting suggestions that nitrogen is a limiting factor to the establishment of vegetation on recently deglaciated sites. In fact evidence shows that most arctic plants are well adapted to nitrogen deficiencies (Savile,1972). Since the increase in *Alnus* is synchronous, it seems likely that its expansion, at all sites, can be explained by a single factor. Because the Alnus expansion occurs coincidentally across a broad geographical area it seems likely that it is the result of a climatic change.

Alnus is well known for its preference of moist areas, often being found along streams, gullies and swamps. It is, therefore, postulated that the marked increase in this species is due to the development of a wetter climate. Climatic modelling suggests that the mid-latitude climate of the northern hemisphere became cooler and wetter at approximately 6000 B.P. (Kutzbach and Guetter, 1986).

Changes between the Betula zone and the Alnus zone are subtle. The boundary between these two zones is defined by an increase of Alnus. This increase is roughly synchronous (~6 800 BP- ~5 100 BP) at treeline sites from across Canada. It seems plausible that this consistent expansion of Alnus was the result of an increase in moisture caused directly by climate change.

6.4 Zone Three

This zone marks a dramatic change in vegetation. Arboreal vegetation, dominated by Picea mariana, invades to intersperse with the already existing shrub tundra. This zone is generally comparable in composition and timing to forest zones described from eastern Canada which existed from ~4 500 BP until ~3 000 BP (Short and Nichols, 1977; Lamb, 1980; Richard et al., 1982; Engstrom and Hansen, 1985). In diagrams from central Canada the initial zones, beginning as early as 6 000 BP, are described as forest zones (Nichols, 1967a; 1967b; 1970; 1975; Kay, 1979). In western Canada arboreal species expand northwards at ~9 500 BP and persist until between ~7 000 BP and ~6 500 BP (Ritchie, 1976; 1977; 1984; 1985; Ritchie and Hare, 1971; MacDonald, 1983; 1987a; Spear, 1983).

In all these studies climate has been concluded to be the controlling factor for the northward expansion of trees. This is mainly due to the discovery that the mean summer position of the arctic front is coincident with the modern treeline (Bryson, 1966). This suggests that the position of the present day treeline is controlled by climatic conditions related to this boundary.

If changes in climate were responsible for the northward extension of forests during the mid-Holocene the obvious question to follow is why the advancement of treeline occurred so much earlier in western Canada than in the study area and eastern Canada. There are two lines of thought which must be considered. The first is that there was a contemporaneous amelioration of climate throughout northern Canada at ~ 9 500 BP which was sufficient enough to allow the expansion of arboreal species. This would imply that in the study area Picea remained out of equilibrium with climate until ~5 000 BP; perhaps as a result of a migration lag or edaphic conditions. The second point is that climatic warming near treeline was not synchronous across Canada. That is, that the climate in western Canada became warmer earlier than at the present study sites.

The possibility that the delay in the arrival of Picea is the result of a migration lag is unlikely. The wind direction and intensity at ~9 000 BP favoured a rapid expansion of Picea to areas near to and perhaps including the study sites (Ritchie and MacDonald, 1986). In fact, Picea was present at Lac Demain only about 350km southwest of McMaster and Queen's Lake by at least ~8 500 BP (Macdonald, 1987a).

Comparing the geology of areas inhabited by Picea at ~9 500- ~8 500 BP with areas where Picea continued to be absent until ~5 000 BP provides some interesting results. The bedrock of the MacKenzie River Basin, the Tuktoyaktuk Penninsula and northern Alberta is comprised mainly of sedimentary rocks including shales dolomites and siltstones, usually with a thick cover of medium to fine-grained glacial deposits (MacDonald, 1987a; 1987b; Ritchie, 1984; 1985). The geology of the present study area is predominantly granitic-gneiss typical of the Canadian Shield with large expanses of bare rock. It is possible that the establishment of Picea at the study sites was delayed by slow rates of soil development on the large expanse of barecrystalline shield rock; while in western Canada the calcic nature of the sedimentary strata and relatively thick and continuous fine-grained glacial overburden facilitated its establishment.

It would follow that changes in edaphic conditions and soil development over time would allow Picea to become established providing that a warm climate persisted. If the inhabitation of Queen's Lake and MacMaster Lake by Picea was controlled by soil development then a gradual increase in its population would be expected. However, the increase in Picea is dramatic suggesting that the factor limiting its expansion must also have been modified suddenly. This leads to the consideration of asynchronous climatic warming.

The pollen records from western Canada (Ritchie, 1976; 1977; 1984; 1985; Ritchie and Hare, 1971; MacDonald, 1983; 1987a; Spear, 1983) are consistent with climatic modelling. An expansion of Picea at ~9 500 BP is coincident with the Milankovitch thermal maximum at ~10 000 BP (Ritchie et al., 1983). Recent modelling by Kutzbach and Guetter (1986) is also compatible with this palynological evidence.

Their model indicates that changes of perihelion caused changes in seasonal radiation which reulted in warmer summers and cooler winters from ~12 000 to ~6 000 BP, with maximum summer warming occurring at ~9 000 BP.

There are two feasible explanations for the lack of coherence between the climatic models and the pollen diagrams from the study area. The first involves the limitations of the climatic models. Presently none of the models include a parameter for the influence of <u>remnant</u> glacial ice (Kutzbach and Guetter, 1986). Ritchie et al. (1983) emphasize the importance of remaining Laurentide ice on the climate in eastern and central Canada. It has been proposed that maximum warming could have been delayed by ice until ~ 6 000 BP (Kutzbach and Guetter, 1986). Trees, however, did not arrive in eastern Canada until ~5 500 BP to ~3 500 BP. Although the delay in forest vegetation in eastern Canada is believed to be due to the persistence of glacial ice other factors may have been involved in this delay. The influence of maritime air (Short and Nichols; 1977) and the barrier to migration of vegetation created by the Gulf of St. Lawrence (Lamb, 1980) have been suggested as factors which further deterred forest establishment.

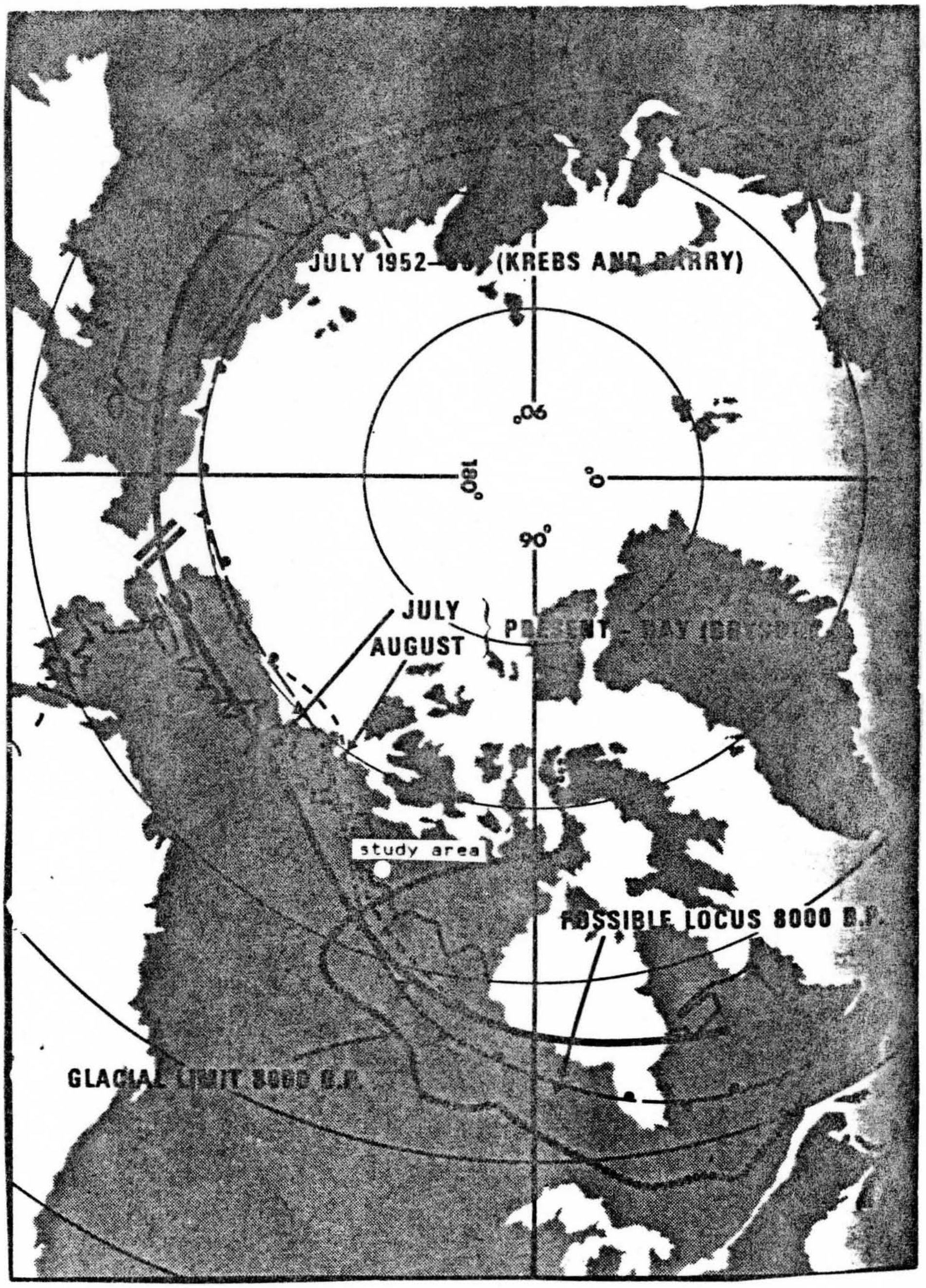
However, the existence of late glacial ice in the study area is debatable. Bryson et al. (1969) indicate that the study area was not ice free until between ~8 000 BP and ~7 500 BP, and that ice remained close to these sites until

~7 000 BP- ~6 500 BP. This deglacial reconstruction provides remnant ice which would have effectively depressed climatic warming until at least ~6 500 BP. However, Dyke and Prest (1987) indicate that deglaciation of the study area ocurred by ~9 000 BP and that no ice existed by ~ 8 400 BP. This reconstruction would not provide a means to explain a delay of climatic warming to ~5 000 BP. Dating control in the area is poor (Dyke and Prest, 1987) so either reconstruction is plausible. From the available research, it is impossible to conclude whether or not ice delayed climatic amelioration.

Yet there is a third possibility. It concerns the properties of the long-wave westerly disturbance (Ritchie and Hare, 1971; Hare, 1973; 1976). The long-wave westerly disturbance behaves in such a way that if temperatures become warmer in the west, causing a northward displacement of the pacific air mass (and therefore the arctic front); an automatic southward displacement of the arctic air mass (and therefore, the arctic front) will occur in the east. This phenomenon was described by Namais (1970) to explain a western warming trend accompanied by an eastern cooling trend that occurred in the 1960's.

Combining these ideas with palynological data the mean July temperature of the arctic front at ~8 000 BP was reconstructed (figure 39, Ritchie and Hare, 1971). Notice that at ~8 000 BP the arctic front is north of its present position in the west, but south of its present position in

Figure 39: **8 000 BP arctic front position.** This diagram illustrates a reconstruction of the arctic front at 8 000 BP with consideration of the long-wave westerly effect (from Ritchie and Hare, 1971).


JULY 1952– (KREBS AND BARRY)
90°
180°
0°
90°
JULY
AUGUST
PRESENT - DAY (BRYSON)
study area
POSSIBLE LOCUS 8000 B.P.
GLACIAL LIMIT 8000 B.P.

the east. Consequently, warm temperatures in the west allowed the advancement of the treeline, while in the east cool temperatures retarded it.

All of these hypotheses are speculative. It is conceivable that the delay in the arrival of Picea to the study area relative to its arrival in western Canada may be the result of a combination of these factors. That is, perhaps the persistence of ice combined wih the long-wave westerly disturbance suppressed temperatures , making the establishment of arboreal species in the study area difficult but not impossible. The combination of cold temperatures with the bare shield rock created an environment so harsh that the expansion of trees was delayed.

6.5 Zone Four

The vegetation at McMaster and Queen's Lake has changed little since ~3 700 BP. A tundra environment has existed until the present. The onset of this zone is defined by the decrease of Picea. Similar declines in forest vegetation have been reported in other Canadian treeline studies. Pollen diagrams from eastern study areas depict the development of modern vegetation at ~3 500 BP, similar to the establishment of modern vegetation at McMaster and Queen's Lake (Short and Nichols, 1977; Lamb, 1980; 1984; Richard et al., 1982; Engstrom and Hansen, 1985). However, in western Canada modern vegetation has existed since ~6 000 BP (Ritchie 1976; 1977; 1984; 1985; Ritchie and Hare, 1971; Spear, 1983; MacDonald and Ritchie, 1986; MacDonald, 1987a).

All previous studies have attributed the disappearance of forest vegetation to cooling. Kutzbach and Guetter (1986) proposed that at middle and high latitudes maximum summer warmth had occurred by ~6 000 BP. A cooling trend followed this period of maximum warmth. One would assume that the decline of arboreal populations, as revealed in pollen diagrams, would define the period when temperatures became too cold to support a forest vegetation. If this assumption were correct then the palynological evidence suggests that the climate in western Canada deteriorated more quickly than in central or eastern Canada. This delay in cooling can be resolved by the behaviour of the long-wave westerlies (see 6.3).

The reduction of forest vegetation may not have been an instantaneous response to climate. That is, trees may have been able to persist in areas climatically unfavorable to their establishment, but not their growth. The existence today of scattered krummholz (clumps of stunted spruce) well beyond the treeline are evidence of this. It has been suggested that the northernmost trees in Canada are relicts of a warmer period (Larsen, 1965; Nichols, 1976; Elliott, 1979; 1983; Payette and Gagnon, 1979; 1985; Payette et.al., 1985; Spear, 1983). It is believed that deterioration in climate prevented the production of viable seeds and/or the conditions necessary for seed germination. Black and Bliss (1980) provided evidence by documenting the failure of *Picea mariana* seeds to germinate, under field conditions, at temperatures of less than 15 C. The production of seeds by these northernmost trees is debatable. Elliott (1979; 1983) indicates that viable seeds are produced by *Picea* at its northern limit in central Canada, but not in eastern Canada. Payette and Gagnon (1979) indicate the lack of seed production by northern populations of *Picea* in eastern Canada. However, Payette et al. (1982) provide evidence that given optimal conditions, these northern *Picea* will produce seeds. Generally, northern *Picea* populations persist by asexual reproduction (layering) (Legere and Payette, 1981). Thus, it has been hypothesized that *Picea* has continued to exist north of environments favorable to seed production and seed regeneration through layering. If this is the case, and the existence of forests north of the present-day treeline at some time following deglaciation is correct, then one might expect the existence of more extensive forests. However, it is believed that fire destroyed most of these historical forests, leaving only scattered patches of trees which are only able to reproduce vegetatively (Larsen, 1965; Nichols, 1976; Elliott, 1979; 1983; Payette and Gagnon, 1979; 1985; Payette et.al., 1985). Once a forest is burned it cannot regenerate unless climatic conditions are favorable for seed germination.

CHAPTER 7 CONCLUSIONS

The pollen and sediment stratigraphy of two lakes, McMaster and Queen's, was analyzed with the aid of twenty-eight surface samples which served as examples of modern vegetation/ pollen deposition relationships. The vegetational history of these tundra lakes was reconstructed and compared to similar histories from other treeline sites from across Canada. The results of this study suggest the following conclusions:

1) The modern pollen spectra and statistical analysis indicate that it is difficult to differentiate the forest, forest-tundra, and the tundra ecotones with modern pollen assemblages. DCs calculated using SEDM provided the best statistical means to distinguish these zones. This indicates that it is subtle differences in medium to low occurance pollen taxa which distinguish the modern vegetation zones in the pollen record.

2) *Betula* grain-size measurements failed to aid in distinguishing vegetation zones in the pollen record. Changes in the organic content of sediment (LOI) , however, were useful in characterizing the three zones. Increases in forest vegetation coincided with increased organic content in lake sediments.

3) No modern analogues exist for fossil pollen assemblages prior to ~5 250 BP. Fossil pollen assemblages from ~5 250 BP until ~5 000 BP are most like pollen assemblages from north of treeline. From ~5 000 BP to ~3 500 BP fossil pollen assemblages are similar to modern pollen from sites south of the treeline, especially in the forest. Following ~3 500 BP fossil pollen samples become increasingly similar to the assemblages from the tundra.

4) The pollen stratigraphies from McMaster and Queen's Lake are almost identical. Sediment focussing throughout the Queen's core and in the upper portion of the McMaster core causes some distortion. Small differences in the relative abundance of some species is due to local variation. The larger PAR and CHAR at McMaster Lake is a result of its smaller size.

5) The basal zone or Betula zone represents a Betula dominated shrub tundra characterized by the early development of bog environments. It spans from ~7 000 BP to ~6 000 BP. Chronological differences in the establishment of this zone with similar zones described from eastern and western Canada can be related to unique deglaciation histories. The existance of a moister and more acidic environment, partially due to the geology, resulted in the bog-like habitat which favoured the development of Ericaceae, Myrica, and Sphagnum.

6) Zone two existing from ~6 800 BP to ~5 000 BP at Queen's

Lake and from ~5 500 to ~5 000 BP at McMaster Lake, is marked by an increase in <u>Alnus crispa</u> and <u>Alnus incana</u>. A shrub tundra persists through this zone. This increase is synchronous across northern Canada and is attributed to an increase in moisture. The difference in age of zone two from McMaster Lake and Queen's Lake is most likely explained by a larger component of exotic pollen into Queen's Lake as a result of its larger size or by a dating error.

7) Zone three delimits the establishment of forest vegetation resulting from the expansion of <u>Picea mariana</u>. It spans from ~5 000 to ~3 500 BP. A similar expansion is described from western Canada, but it occurred ~4 000 years earlier. The delay of <u>Picea mariana</u> expansion to the study area can be explained by one of the following:

i) geological differences;
ii) remnant glacial ice;
iii) The long-wave westerlies; or
iv) some combination of the above.

8) The modern tundra zone is delineated by the decline of <u>Picea mariana</u> and marks the establishment of modern the tundra vegetation at both sites. Climatic cooling and failure to reproduce following fire are likely the regional and local factors responsible for the extinction of the forest north of present-day treeline.

9) This study demonstrates the importance of considering factors other than climate, such as hydrological and edaphic

conditions, geology, fire, biological interactions and autecology, in the reconstruction and interpretation of past vegetations.

Ba

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