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PAPER 72-49

PALYNOLOGICAL STUDIES IN CENTRAL SASKATCHEWAN

Pollen Stratigraphy from Lake Sediment Sequences

R. J. Mott

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Pollen Stratigraphy from Lake Sediment Sequences

(Report and 5 figures)

R. J. Mott

DEPARTMENT OF ENERGY, MINES AND RESOURCES

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ABSTRACT

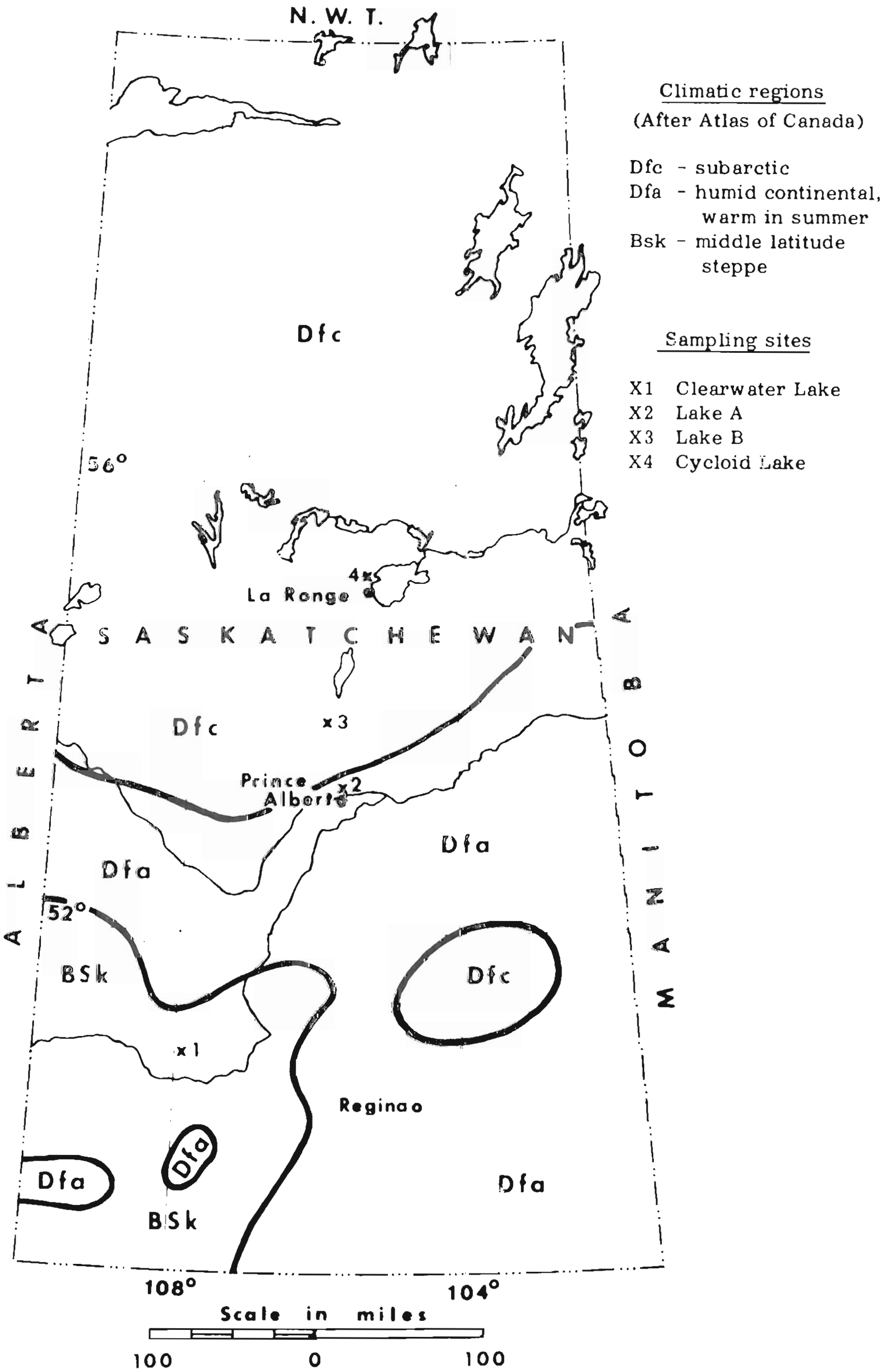
Lake sediment sequences from four sites in central Saskatchewan were studied as part of a project to determine the late-glacial and postglacial vegetational and climatic history of the area. Several radiocarbon dates help to outline chronology.

Boreal vegetation dominated by Picea invaded the area as the ice retreated northward. Progressively younger radiocarbon dates on the Picea zones, 11,560 ± 640 (GSC-648) at Prince Albert, 10,260 ± 170 (GSC-647) within Prince Albert National Park, and 8,520 ± 170 (GSC-643) near La Ronge, mark the migration northward. About 10,000 years B.P. a warmer and less humid climate caused grasslands to replace the boreal vegetation in the south and grasslands prevailed to the present in the Clearwater Lake area on the Missouri Coteau. Grassland vegetation also invaded the Prince Albert area and, although open grasslands did not extend as far north as the study site within Prince Albert National Park, a parkland type of environment may have existed for a short time. The grasslands retreated with the return of a cooler and more humid climate and a mixed wood forest developed in the Prince Albert National Park areas. In the La Ronge area the Picea-dominated vegetation gave way to a mixed wood forest and then, after about 6000 ± 170 years B.P. (GSC-1335), a coniferous forest gradually developed.

RÉSUMÉ

Des séries de sédiments lacustres situés en quatre endroits au centre de la Saskatchewan ont été étudiées dans le cadre d'un projet qui a pour but de préciser l'histoire régionale de la végétation et du climat tardiglaciaires et postglaciaires. Plusieurs datations du radiocarbone ont servi à établir la chronologie.

La végétation boréale dominée par Picea a envahi la région au fur et à mesure de la retraite de glaces vers le nord. Les dates au radiocarbone, qui sont de plus en plus récentes dans les zones à Picea, soit 11,560 ± 640 (CGC-648) à Prince Albert, 10,260 ± 170 (CGC-647) dans le parc national de Prince Albert, et 8,520 ± 170 (CGC-643) près de La Ronge, indiquent une migration vers le nord. Il y a environ 10,000 ans B.P. grâce à un climat plus chaud et moins humide, des prairies ont remplacé la végétation boréale au sud et des prairies ont prédominé jusqu'à aujourd'hui dans la région de Clearwater Lake sur le coteau Missouri. Une végétation herbeus a aussi envahi la région de Prince Albert et, bien que la grande prairie ne se soit pas étendue aussi loin vers le nord que l'endroit étudié dans le parc national de Prince Albert, une végétation de parc peut avoir existé pendant une courte période de temps. Au retour d'un climat plus froid et plus humide, la prairie a retraité et une forêt mixte s'est développée dans les régions de Prince Albert et du parc national. Dans la région de La Ronge, la végétation à prédominance de Picea a cédé la place à une forêt de conifères s'est développée petit à petit.


N. W. T.
Climatic regions
(After Atlas of Canada)
Dfc - subarctic
Dfa - humid continental, warm in summer
Bsk - middle latitude steppe
Sampling sites
X1 Clearwater Lake
X2 Lake A
X3 Lake B
X4 Cycloid Lake
Dfc
56°
4x
La Ronge
ALBERTA
SASKATCHEWAN
MANITOBA
Dfc
x3
Prince Albert
x2
Dfa
Dfa
52°
BSk
Dfc
x1
Regina
Dfa
Dfa
Dfa
BSk
108°
104°
Scale in miles
100
0
100

PALYNOLOGICAL STUDIES IN CENTRAL SASKATCHEWAN, POLLEN STRATIGRAPHY FROM LAKE SEDIMENT SEQUENCES

INTRODUCTION

Several lakes of central Saskatchewan were sampled to determine the late-glacial and postglacial geochronology and climatic history of the area. This paper includes the results of palynological studies of four of the lake sediment sequences and the radiocarbon dates obtained.

Earlier palynological studies in Saskatchewan have been limited to late-glacial or early postglacial sites along the Missouri Coteau near Herbert (Kupsch, 1960), near Crestwynd (the Hafichuk site, Ritchie, 1966), southwest of Moose Jaw (Ritchie and deVries, 1964) and near Kayville (the Scrimbit Farm site, Dew, 1959; Terasmae, pers. comm.). In all cases the sites were dry, former lake basins and the pollen profiles were truncated and did not extend to the present.

In a previous paper (Mott, 1969), the author reported contemporary pollen spectra from surface samples collected from various landform/vegetation zones throughout the province. A study of recent pollen assemblages from the western interior of Canada (Lichti-Federovich and Ritchie, 1968) included samples from sites in Saskatchewan. These and other studies of surface spectra from Manitoba (Lichti-Federovich and Ritchie, 1965) and the northern Great Plains of the United States (McAndrews and Wright, 1969) will serve as a basis for interpretation of the fossil pollen assemblages.

As the general physiography and vegetation of Saskatchewan were outlined in the paper on contemporary pollen spectra (Mott, 1969) only the details particular to each site will be dealt with here.

METHODS

Lake bottom sediment cores were recovered using two different sampling devices operated from an anchored raft (Mott, 1966). The core, including the mud/water interface and about 1 to 1.5 m of the underlying sediment, was collected using a Brown sampler (Brown, 1956). All other cores were recovered with a Livingstone sampler (Deevey, 1965) in approximately 1 m increments.

The standard acetolysis method was used to concentrate palynomorphs, hydrochloric and/or hydrofluoric acid being used when warranted. To count them, residues were dehydrated with butanol and mixed with silicon oil. A Leitz Ortholux microscope was used for counting, the counts in all cases exceeding 200 and often exceeding 300 grains.

GEOGRAPHIC DESCRIPTION AND CORE STRATIGRAPHY

CLEARWATER LAKE

Clearwater Lake (Fig. 1) is a small freshwater lake of about 50 hectares (125 acres) located 5 miles E.N.E. of Kyle and approximately 46 miles north of Swift Current (50°52'25"N., 107°56'W.). Water depth is generally less than 2 m with a maximum of about 6 m in one small central area of the lake.

Manuscript submitted: 25 February, 1972
Final version approved: 14 November, 1972

A total of 1270 cm of sediment core were recovered from the lake before bottoming in coarse grey sand which was too thick to penetrate with a hand-operated device. More organic sediment may be present below the sand, but a heavier coring device is required for its recovery. The complete sediment sequence recovered is an organic marl or marly gyttja with varying organic content and numerous sand layers. Organic content generally is about 15 to 20 per cent with higher percentages toward the top of the core and in discrete organic layers. A definite colour change and increase in organic content occurs at about 60 cm of depth, probably indicating the beginning of settlement of the area.

Physiographically the lake is on the Alberta High Plains, a subdivision of the Great Plains Province of the Interior Plains (Acton et al., 1960). It lies in a closed depression (kettle hole) in an area of ridges moraine, designated the Clearwater Lake moraine, and associated hummocky kame moraine (Christiansen, 1959). The local relief varies from 10 to 100 feet and the elevation of the lake is about 2250 feet (686 m) a s.l.

The area is grassland of the Mixed Prairie Association, except on the immediate borders of the lake where some trembling aspen (Populus tremuloides) occurs. Vegetation and ecology of the mixed prairie has been described by Coupland (1950, 1961).

LAKE A

Lake A (Fig. 1) lies partially within the boundaries of Nisbet Provincial Forest about 2 1/2 miles northeast of the bridge over the North Saskatchewan River at Prince Albert (53°14'15"N., 105°43'30"W.). The lake is at an elevation of 1445 feet (440 m) and covers an area of about 25 hectares (62 acres) with a maximum water depth of 1 m or less. About 590 cm of marl and banded organic marl and gyttja overlie 3 to 4 cm of coarse organic detritus which, in turn, overlie organic sand grading downward into dark grey, coarse sand.

Although the surrounding area is classified by Acton et al. (1960) as the Saskatchewan Plains Region of the Great Plains Province, the lake is located in a narrow finger of the Manitoba Saskatchewan Lowlands of the Central Lowlands Province, which extends up the North Saskatchewan River. Both provinces make up the Interior Plains Division. The lake occupies a closed depression in an area of stabilized sand dunes. Following deglaciation, a glacial lake, which had formed in the low-lying area between the ice and the higher land to the south and southwest, covered the area. With further retreat of the ice front, the lake drained and the ancestral North Saskatchewan River began to flow through the valley. The sand is probably of alluvial origin although it may be partly a lacustrine sand. Dune activity was prevalent before vegetation stabilized the sand.

Rowe (1959) includes this area in the Mixedwood Section of the Boreal Forest Region and this classification is composed of forests of white spruce (Picea glauca), trembling aspen, balsam poplar (Populus balsamifera), white birch (Betula papyrifera), black spruce (Picea mariana) and some tamarack (Larix laricina) and balsam fir (Abies balsamea). In the sand dune area, the forest is locally dominated by jack pine (Pinus banksiana).

LAKE B

Saskatchewan highway number 2 through Prince Albert National Park passes the west end of Lake B (Fig. 1), a small lake of about 25 hectares (62 acres) 9 miles south of Waskesiu (53°48'N., 106°04'45"W.). Maximum water depth is three metres. Dark, greenish-brown gyttja with slightly calcareous, lighter layers grades downward into a coarsely laminated organic marl and gyttja at 350 cm below the mud/water interface. Below this, the sediment becomes more finely laminated and contains more marl to a depth of about 450 cm where laminations become coarser again and the organic layers become more abundant. Below 495 cm the sediment is dark, greenish-black silty gyttja with woody and other coarse organic fragments which becomes more silty towards the contact with coarse, pebbly silt and clay at 510 cm. Some needles of spruce (Picea) and possibly balsam fir are present in the sediment immediately above the contact.

Lake B is also within the Great Plains Province of the Interior Plains but within the Saskatchewan Plains Region. The surrounding rolling topography is of glacial origin. The lake occupies a closed depression suggesting the presence of stagnant ice blocks after deglaciation. Because it is an upland (elevation 1750 feet or 553 m) no glacial lakes covered the area (Richards and Fung, 1969).

The surrounding forest is mixed with white spruce, trembling aspen, balsam poplar and jack pine predominant on the upland sites and black spruce and tamarack occupying the wet areas. Rowe (1969) includes the area in the Mixedwood Section of the Boreal Forest Region.

CYCLOID LAKE

Cycloid Lake (Fig. 1) is 10 miles due north of La Ronge along the west side of highway number 2 to Otter Rapids (55°16'N., 105°16'W.). The lake is at an elevation of about 1300 feet (369 m), covers an area of about 20 hectares (50 acres) and has a maximum water depth of 2 m. A total of 327 cm of algal gyttja, which is dark brown with little coarse plant detritus at the mud/water interface, grades into a gyttja with abundant coarse detritus at the contact with the underlying mineral sediment. Below the contact, silt and clay gradually become more abundant in the grey-brown organic silt and clay until a stiff blue-grey clay is encountered at 340 cm.

The lake is bordered on the south and southwest by a large knob of Precambrian bedrock and on the other sides by low-lying boggy land. A small stream drains the basin to the northeast into Lac La Ronge. Drainage into the lake is very local.

Cycloid Lake is situated on the southern edge of the Canadian Shield in the Churchill River Plains Region of the Churchill Province (Acton et al., 1960). The area is a bedrock knob complex with overlying glacial deposits. Some glacial lacustrine sediments occur in the lower areas as a result of an arm of glacial Lake Agassiz covering the area following deglaciation (Prest et al., 1967; Elson, 1967).

Rowe (1959) includes this area in the Northern Coniferous Section of the Boreal Forest Region. Black spruce is abundant and is associated with jack pine on the drier sites and with tamarack on the poorly drained areas. White spruce, balsam fir, trembling aspen, and balsam poplar are prominent on better sites. Immediately surrounding the lake, jack pine is prominent on the bedrock outcrops and black spruce on the low, wet areas.

CLIMATE

The climate of Saskatchewan varies widely from south to north as seen in the dry steppe climate of the southwest and the contrasting subarctic climate of the north. The pertinent climatic data shown on Figure 1 and outlined below were gleaned from the Atlas of Canada (1957), Thomas (1953), Kendrew and Currie (1955) and Richards and Fung (1969).

The southwest part of the province, generally the area above the Missouri Coteau, which includes the Clearwater Lake area, has a dry climate designated as middle latitude steppe. Strong winds characterize the area most of the year with southwest winds prevailing in the winter, bringing in mild Pacific air. Colder temperatures follow shifts to the northwest in the wind direction. Winds from the southwest are frequent in the summer causing warm and dry conditions but northwest and especially southeast winds are also common. The mean annual temperature is about 35 degrees F with a mean January daily temperature of about 5 degrees F and mean July daily temperature of 68 degrees F. The mean annual total precipitation is about 15 inches, of which about 10 inches falls as rain. The potential loss through evaporation is greater than the precipitation received.

The climate of the Lake A area near Prince Albert is classified among the humid microthermal climates, a humid continental climate with cool summers and no dry season. Winds are not as strong as in the open prairie and vary from northwest and west in the winter to southeast and east in the summer. The mean annual temperature is about 32 degrees F and the mean daily January and July temperatures are -3 degrees F and 65 degrees F respectively. About 15 inches of precipitation is the mean annual total, of which about 10 inches fall as rain.

Climatically, the area around Lake B is subarctic. Wind directions are variable with no seasonal prevalence and, because of the forest cover, the speed is less than in the open prairie. The January and July mean daily temperatures are about -4 degrees F and 62 degrees F respectively with an annual mean of 31 degrees F. Here also about 10 inches of the total annual precipitation falls as rain.

Subarctic climate also characterizes the Cycloid Lake area which has a mean annual temperature of 30 degrees F. The January mean daily temperature of -10 degrees F contrasts with that in July of 62 degrees F. Also, the winds are lighter because of the forest cover and are variable in direction throughout the year. Of the mean annual total precipitation of 15 inches, 10 inches fall as rain.

The climatic regions outlined above are classified according to the Koeppen system which relates the main climatic boundaries to the main vegetation boundaries. Using analyses of air mass frequency distribution and wind streamlines, Bryson (1966) has defined distinctive climatic regions based on the dominance of various air masses. These climatic regions show congruence with several major biotic regions but provide a method of defining climatic regions independently of vegetational boundaries. Various vegetation regions are seen to have distinctive climates determined by the prevalence of a particular air mass or masses and, presumably, these vegetation regions are where they are today as a result of the climate. This approach appears particularly useful in determining the character of late-glacial and postglacial climates (Bryson and Wendland, 1967; Bryson et al., 1970). If enough information concerning the biota of a period is known, the climatic character of the region can be defined.

RADIOCARBON DATES

Table 1 lists the radiocarbon dates obtained for the four sites dealt with in this paper. At Clearwater Lake radiocarbon age determinations on the basal sediment yielded a date of 9310 ±150 years B.P. (GSC-1506[2]) for the inorganic or carbonate portion of the sediment whereas the organic portion of the same sample produced a date of 7580 ±220 years B.P. (GSC-1506[1]). A discrepancy of 1730 radiocarbon years indicates that dead carbon, probably from ancient carbonate sediments, was present in the lake. If this assumption is accurate, some dead carbon was also incorporated into the organic portion of the sediment due to uptake by the organism that produced the sediment, and the date on this portion of the sediment would also be in error. In order to gain some insight into the magnitude of the error involved in the anomalous dates, a radiocarbon age determination on sediment near the mud/water interface was attempted. The interval from 60 to 70 cm was chosen because the change in lithology of the core and changes in pollen assemblages were interpreted as a reflection of the influence of modern settlement of the area. Dates of 1170 ± 190 years B.P. (GSC-1563[1]) and 1260 ± 190 years B.P. (GSC-1563[2]) were obtained for the organic and inorganic portions respectively.

According to the Atlas of Saskatchewan (Richards and Fung, 1969) the main influx of settlers occurred during the decade 1901-1911. If the interpretation concerning the top 60 to 70 cm of sediment mentioned above are correct, then this sediment was probably deposited during the last 60 to 70 years and the error involved due to incorporation of old carbonates would be of the order of 1100 radiocarbon years. This means a rate of sedimentation of 1 cm/year which seems high but is only 5 to 6 times greater than the rate needed to deposit 1260 cm in 7500 years. With the added input of essential nutrients into an already eutrophic lake, this higher rate of sedimentation may not be out of order. However, if the upper 60 to 70 cm were deposited since the lake began to be used for recreational purposes, a date more recent than that of settlement of the area, then the error could be slightly greater than 1100 years. Possibly some other historical event before settlement is recorded in this sediment in which case a smaller error would be involved.

Assuming the error to be about 1100 radiocarbon years, the basal sediment dated is probably no older than 6480 (7580 minus 1100) years B.P. The core was closely scrutinized in an attempt to find the Mazama volcanic ash layer, but it could not be found. The aerial distribution of the ash may not have extended into this area but its recent discovery in a section in the South Saskatchewan River bluffs (David, 1970) west of Clearwater Lake makes its presence a possibility. However, if the age of the basal sediment recovered is no more than 6480 radiocarbon years, then the Mazama ash would not be present.

The basal sediment from Lake A on which the radiocarbon date of 11,560 ±640 (GSC-648) years B.P. was obtained, was an organic debris with some coarse organic fragments and grey-black sand which was not calcareous.

Although it is possible that dead carbon could still be present in any remains of aquatic plants which originally grew in the lake and were subsequently deposited in the sediment dated. the date obtained does not seem to be anomalously old. A radiocarbon date on the near-surface sediment would not give a reliable estimate of the degree of error as this sediment is marl and the basal sediment is not. Therefore, the date is accepted as reliable until further information proves otherwise

Most of the sediment in the Lake B core does contain carbonates. However, the basal sediments, coarse organic debris in pebbly silt and clay and black silty gyttja with woody fragments, are non-calcareous and this was used for the radiocarbon age determination (GSC-647, 10,260 ± 170 years B.P.). Again with the one qualification of possible incorporation of dead carbon into the structure of the aquatic plants, this date should be reliable and, in fact, does not seem to be inordinately old.

The sediment from Cycloid Lake does not contain any trace of carbonates and is not from an area of carbonate bedrock so that it is unlikely that any contamination of this type is present. Both dates obtained can be accepted as reliable.

PALYNOLOGICAL RESULTS

Since the four lakes studied are widely separated geographically and are in different vegetation zones, their pollen assemblages are also grossly different. Therefore, the pollen results cannot be discussed using pollen assemblages common to all four pollen diagrams but must be treated individually, and any similarities they might have must be discussed later.

The pollen assemblage zones used are defined on the basis of kind and number of pollen grains and spores contained in the sediment and are numbered in roman numerals from the top down with no relationship implied between the zones of same number on different diagrams. This is in agreement with the Code of Stratigraphic Nomenclature as applied to pollen stratigraphy as pointed out by Cushing (1964).

Percentages shown in the pollen diagram are based on a pollen sum which includes all pollen types except aquatics and semi-aquatics. These exceptions are calculated separately using the same pollen sum. Sedges (Cyperaceae) are not included in the pollen sum as they occur in both low wet areas and uplands, especially on the prairie, and its inclusion in some pollen sums and not others would lead to confusion. Exotics, such as *Sarcobatus*, are also not included in the pollen sum.

CLEARWATER LAKE

Even though more than 1250 cm of organic sediment were recovered in the core from Clearwater Lake, it is obvious from the radiocarbon dates obtained and the pollen assemblages found that postglacial time is not represented in its entirety. The assemblages throughout the pollen diagram (Fig. 2) are dominated by herb pollen types; tree and shrub pollen types have low relative frequencies. The column showing totals of trees, shrubs and

TABLE I

Radiocarbon Dates

Location	Core interval (cm)	Laboratory dating no.	Uncorrected age (^{14}C years before 1950)	$\delta^{13}C$ (o/oo)	Corrected age (^{14}C years before 1950)	Reference
Clearwater Lake	1250-1260	GSC-1506[1]	7590±220	-26.0	7580±220	
	1250-1260	GSC-1506[2]	9310±150			
	60-70	GSC-1563[1]	1120±190	-22.2	1170±190	
	60-70	GSC-1563[2]	1260±190	2.9		
Lake A	590-620	GSC-648	11560±640			Mott, 1967; Lowdon et al., 1967
Lake B	496-504	GSC-647	10260±170			Mott, 1967; Lowdon et al., 1967
Cycloid Lake	323-328	GSC-643	8520±170			Mott, 1967; Lowdon et al., 1967
	257-262	GSC-1335	6000±170			Mott, 1967; Lowdon et al., 1967

[1] Organic portion of sediment.

[2] Inorganic or carbonate portion of sediment.

herbs illustrates this graphically. Total tree pollen relative percentages never exceed 40 whereas those of all herbs never fall below 50 and are usually more than 70 per cent.

Artemisia pollen types, grass (Gramineae), sedge and chenopod (Chenopodiineae) dominate the Clearwater Lake diagram. Pine, probably lodgepole pine (Pinus contorta), is the only abundant tree genus. Of the shrubs, alder (Alnus) and willow (Salix) are usually present but only in small amounts. The only differences in the assemblages occur at the base and top of the diagram. Ragweed (Ambrosieae) and chenopod pollen types are more abundant at the base. Chenopods also show a sharp increase at about 60 cm of depth as do spores of Selaginella densa, in contrast to the relative abundance of Artemisia which decreases abruptly.

Based on these spectral differences, three zones can be delineated; a Chenopodiineae-Selaginella densa pollen assemblage zone shown as zone C-I, an Artemisia-Gramineae pollen assemblage zone shown as zone C-II, and an Ambrosieae-Chenopodiineae pollen assemblage zone designated C-III.

LAKE A

Because it extends farther back in time, the pollen diagram for Lake A (Fig. 3), has more varied pollen spectra. Based on pollen spectral changes, the assemblages can be divided into five pollen spectral zones.

Zone A-V, the Picea - Cyperaceae pollen assemblage zone is characterized by high relative frequencies of spruce and sedge. Values for other pollen taxa are very low. A sharp decline in both spruce and sedge with increases in birch (Betula) and herb pollen types, notably Artemisia, grasses and chenopods, marks the boundary with the Betula-herb pollen assemblage zone shown as zone A-IV. Spruce and sedge frequencies increase again slightly within the zone but fall to low values toward the top of the zone. Birch values also decrease.

Herb pollen types then become predominant in the Artemisia-Gramineae pollen assemblage zone (A-III). The chenopods are also abundant but spruce and birch have very low frequencies. A general decline in herb pollen frequencies to below 50 per cent and a corresponding increase in birch with slight increases in jack pine (Pinus banksiana) and alder (Alnus) distinguish zone A-II, the Betula-Artemisia pollen assemblage zone. This zone extends upward until jack pine becomes predominant in the Pinus banksiana pollen assemblage zone A-I. By this level birch has declined considerably in relative abundance, alder has declined somewhat and herb pollen frequencies have fallen even lower than in zone A-II. Spruce shows slight increases but does not become prominent.

LAKE B

The column showing tree, shrub and herb pollen totals in the Lake B pollen diagram (Fig. 4) readily illustrates the tripartite aspect of the sequence where spectra dominated by tree pollen are separated by spectra in which herb pollen types, though not predominant, are abundant. Subdividing the herb pollen and upper tree pollen spectra further yields five pollen assemblage zones.

At the base of the diagram zone B-V, the Picea pollen assemblage zone, encompasses the spruce peak. Spruce values vary from 50 to almost 90 per cent whereas relative frequencies of other taxa remain low. Higher relative frequencies of herb pollen types, especially Artemisia, grasses, sedges and chenopods characterize the next two zones. In the zone above B-V, spruce pollen has declined considerably but is still abundant, birch has increased slightly and major herb pollen types have increased. This Picea-herb pollen assemblage zone is designated B-IV. Spruce pollen frequencies continue to decline in the next zone as jack pine increases to a peak and then decreases. The relative frequencies of birch and alder increase gradually and herb pollen types are still abundant. This Pinus banksiana-herb pollen assemblage zone is shown as B-III.

In zone B-II, the Pinus banksiana-Betula pollen assemblage zone, jack pine increases again, birch reaches a maximum and herb totals have declined still further. Jack pine becomes the prominent species in the Pinus banksiana pollen assemblage zone designated B-I. Birch has declined but is still abundant and spruce has increased somewhat over its low values below.

CYCLOID LAKE

The Cycloid Lake diagram (Fig. 5) can be divided into five pollen assemblage zones. The lowest, zone Cy-V or Picea-Salix pollen assemblage zone, is characterized by assemblages with abundant relative frequencies of herb pollen types, especially Artemisia, grasses, sedges and chenopods, spruce percentages below 45, birch between 15 and 25 per cent and willow (Salix) pollen in significant amounts. Soapberry (Shepherdia canadensis) is another shrub pollen type consistently present in small amounts. Aspen (Populus) is also present in small numbers, which may still be significant as it is even less abundant higher in the core.

An increase in the relative abundance of spruce pollen which attains values exceeding 60 per cent distinguishes the Picea pollen assemblage zone Cy-IV. Birch values remain between 15 to 25 per cent and shrub and herb pollen percentages decrease somewhat but are still higher than in later times. Zones Cy-III, or the Betula-Alnus pollen assemblage zone, begins with a decline in spruce which eventually drops to relative values of less than 10 per cent. Birch increases greatly, with less increases by alder whereas other shrubs and herbs decrease.

Spruce pollen values remain low in the Pinus banksiana-Betula pollen assemblage zone (Cy-II) but jack pine begins to rise and attains relative frequencies of more than 50 per cent before again declining to lower values. Birch and alder percentages decrease with the increase in pine but recover as pine decreases. The boundary between zones Cy-II and Cy-I is placed where pine reaches its minimum values before increasing again and where spruce increases to percentages greater than ten. The relative abundance of spruce and alder remains fairly constant throughout the Pinus banksiana pollen assemblage zone (Cy-I), jack pine increases almost to 50 per cent and gradually declines to about 30 per cent, which is its level at the present time. The reverse is true of birch which increases to about 35 per cent.

DISCUSSION

Unfortunately, the core recovered from Clearwater Lake did not span all postglacial time. As discussed in the section on radiocarbon dates, the age of the basal sediment dated is probably no more, and may be somewhat less, than about 6500 radiocarbon years old.

The pollen assemblages throughout the sequence are dominated by herbaceous pollen types indicating that prairie conditions prevailed in this area during the time represented by deposition of the sediment. The relative abundance of pine (Pinus) pollen which reaches a maximum of about 33 per cent, but is generally less than 20 per cent, can be attributed to long distance transport. Percentages of this magnitude were obtained by the author in surface samples from prairie environments (Mott, 1969). As the frequency of southwest winds is high in early summer in southwestern Saskatchewan, the source of pine pollen may be the Cypress Hills and the highest percentages may indicate an increase in lodgepole pine (Pinus contorta) in that area.

The main changes which occur in the diagram involve the relative frequencies of various herb pollen types. The combined effects of climate, grazing, fire and many other parameters are difficult to ascertain and little work has been done to determine the vegetational changes which occur in response to variations in these parameters in the prairie environment. Studies by Clarke et al., (1947), Coupland (1950, 1959) and Coupland et al., (1960) report various changes in vegetation due to a change in climate and grazing practices. Usually only the forage plants are considered and, in some cases, the results are contradictory. However, their conclusions may shed some light on the spectral changes seen in the pollen diagram. These studies show that Artemisia frigida, a prominent species, decreased under drought conditions while some species in the Chenopodiineae and Compositae increased. Some grasses are favoured by drought while others suffer greatly. In zone C-III the higher percentages of Chenopodiineae and Ambrosieae pollen types with lower Artemisia values probably indicate drier conditions. The reverse trends in zone C-II would then indicate a change to a more favourable climate.

The principal forb Artemisia frigida decrease with grazing whereas some species of Chenopodiineae increase and Selaginella densa, a very abundant species in the Manyberries area of Alberta (Clarke et al., 1947) whose basal area equals that of all other species combined, is also favoured. Van Dyne and Vogel (1967) found the reverse to be true of the latter species in areas of Montana. The assemblages encompassed by zone C-I which show decreases in Artemisia with accompanying increases in Chenopodiineae and Selaginella densa, may indicate increased grazing. This interpretation would support the conclusion that the top 60 to 70 cm of sediment were deposited since settlement of the area.

Absolute frequencies would be extremely useful in the study of grassland pollen assemblages to determine if the pollen abundances reflect real changes in various species or not. More work is also required to determine the effects of various ecological parameters on vegetation.

Earlier studies of other sites in southern Saskatchewan, notably the Herbert, Hafichuk, Crestwynd and Scrimbit Farm sites where palynological studies are associated with radiocarbon datings, have shown that trees were present from at least 11,700 radiocarbon years B.P. (S-83, Parizek, 1964) until about 10,000 radiocarbon years B.P. (S-41, Kupsch, 1960). The relative abundance of spruce (Picea) pollen in the assemblages indicates that, if spruce trees did not form a closed forest, they were locally abundant on favourable sites. The Crestwynd site (Ritchie, 1966) shows that by 9390 radiocarbon years B.P. the flora was dominated by grassland types and spruce was very scarce. More work on continuous sequences involving late-glacial through postglacial time is required before details of the vegetational changes can be determined.

At Prince Albert the base of the core recovered from Lake A provided a radiocarbon date that is the oldest in an area this far north in Saskatchewan and, despite the presence of carbonates higher in the core, the date seems reliable. Zone A-V or Picea-Cyperaceae zone is similar to basal zones described by Ritchie (1964, 1966) and Ritchie and Lichti-Federovich (1968) in Manitoba and Lichti-Federovich (1970) in Alberta. The spruce is accompanied by abundant sedge (Cyperaceae) pollen with soapberry (Shepherdia canadensis) and willow (Salix) consistently present in small amounts. As Ritchie and Lichti-Federovich (1968) have stated, modern analogues of this assemblage have not been found. Populus is not as prominent as Lichti-Federovich (1970) found in Alberta and pollen of such deciduous elements as ash (Fraxinus), elm (Ulmus) and oak (Quercus), unlike diagrams from Manitoba (Ritchie and Lichti-Federovich, 1968), are virtually absent. Some herb pollen frequencies increase slightly within the zone but do not become abundant. The vegetation represented by this type of pollen assemblage is pictured as a closed spruce forest with abundant shrubs of willow and soapberry on suitable sites. The lack of herb pollen types of plants requiring open dry areas for growth indicate that sedge was probably abundant in wet areas surrounding lakes and in other low areas.

By the beginning of zone A-IV spruce and sedge pollen had declined greatly, birch (Betula) had increased somewhat and herbs had increased considerably. Modern matching analogues of this assemblage are also lacking, the closest resemblance being among assemblages of the mixedwood section of the boreal forest, except that pine percentages are very low. Such low percentages of pine pollen can be attributed to long distance transport (Terasmae and Mott, 1965) and indicate that pine probably did not grow in the area. A more open forest is suggested with spruce and birch on mesic sites, the xeric sites supporting grass-sedge-herb communities.

The continued increase in herb pollen frequencies in zone A-III, and further declines in tree and shrub totals, resulted in pollen assemblages analogous to those of present day grassland regions in southern Saskatchewan (Mott, 1969) and to assemblages that prevailed throughout most of the time represented on the Clearwater Lake diagram. Judging from the relative percentages of Artemisia, Chenopodiineae and Selaginella densa, the pre-settlement type of grassland vegetation (zone C-II) with more Artemisia prevailed as would be expected.

A decline in herb pollen totals and increases in birch, alder (Alnus) and willow which characterize zone A-II suggest a return to more forested conditions. These genera certainly increased and, despite the low frequencies of Populus, aspen probably increased also. The vegetation was still open enough to support abundant herbs as is reflected by the total herb pollen percentages of 30 to 50 per cent. Pine pollen percentages increased but not to the extent that they cannot be accounted for by long distance transport.

The invasion of jack pine (Pinus banksiana) into the area is marked by sharp increases in pine pollen in zone A-I. Spruce pollen also increased indicating a return of spruce to the area in more significant numbers. The decline of birch and alder pollen may not mean as great a decrease in these genera as the relative frequencies indicate because of the method of calculation. Relative frequencies of herbs which fall below 20 per cent reflect the closed nature of the forest at that time.

The pollen assemblages outlined for the Lake B diagram show some similarities to the Lake A zones. The basal zone (B-V) is also dominated by spruce pollen but sedge percentages are much lower. A closed spruce forest is indicated as in the Prince Albert area although here the age of the spruce maximum is about 10,260 years B.P.

In zone B-IV the lower relative frequencies of spruce pollen and increases in grasses, sedges and Artemisia reflect a decrease of spruce in the area and an incursion of herbs into open upland sites.

Total herb pollen content increases in zone B-III but not enough to indicate prairie conditions. Open parkland similar to the present aspen parkland may have prevailed and aspen may have been abundant even though large amounts of aspen pollen were not found Birch and alder must have increased and spruce declined considerably. The increase in pine pollen values to more than 30 per cent does not require large increases in pine in the immediate area of the lake but it probably does indicate small increases in the general region, possibly a migration of pine toward the region.

A zone B-II may not be warranted as major changes in pollen assemblages are not involved, and this assemblage could be included in zone B-III. However, it is delineated to show the continued rise in birch and decline in herbs and a resurgence of pine following the decline towards the top of zone B-III.

Zone B-I, with its increase in pine and spruce pollen and sharp decline in birch, reflects the migration of pine into the area and a return of spruce. Birch probably did not decrease as much as the relative percentages indicate. This assemblage prevails to the surface showing that the present mixedwood forest was constituted about the time of the beginning of zone B-I.

The diagram from Cycloid Lake has a pollen assemblage below the spruce maximum which is denoted as zone Cy-V and, although spruce pollen is abundant, it does not reach values nearly as high as in the spruce zone. Similarities in the constituent taxa, but not necessarily in their relative frequencies, can be seen in the basal assemblage from Lofty Lake in Alberta (Lichti-Federovich, 1970) and at some sites in Manitoba (Ritchie and Lichti-Federovich, 1968). Modern surface spectra analogous to this pollen assemblage have not been found. Spruce and birch were present on the landscape as was aspen, willow and soapberry despite their low relative pollen frequencies. Artemisia, sedges, grasses and chenopods were also present.

Spruce became the dominant pollen in zone Cy-IV denoting an increase in spruce and formation of a closed spruce forest. This occurred in the Lac La Ronge area about 8500 years B.P. as noted by the radiocarbon date. Birch then increased greatly and spruce declined as indicated by the assemblages in zone Cy-III. Alder also increases considerably as spruce declines even more.

About 6000 years B.P. jack pine began to invade the area and, in a short time, increased in relative abundance to values exceedding 50 per cent. No doubt jack pine was more abundant in the area at that time than at present, judging by the relative frequencies. Pine values exceeding 50 per cent in modern assemblages are found in diverse localities throughout the boreal forest only where it is locally abundant (Mott, 1969; Lichti-Federovich and Ritchie, 1965).

Pine pollen values recover again in zone Cy-I following a decline toward the Cy-II/Cy-I boundary, probably indicating a resurgence of pine in the area. Spruce also became more abundant. The modern forest type then came into being as jack pine declined again and birch increased.

CONCLUSIONS

Evidence from several sites along the Missouri Coteau in southwestern Saskatchewan reveal the presence of spruce trees in the area in late glacial time. Wood, cones and needles as well as abundant spruce pollen indicate that spruce formed either a closed forest or was very abundant on suitable sites. That spruce grew in widespread areas of what is now prairie can be seen from the occurrences of macrofossil and pollen evidence in several states of the American midwest. Wright (1970, 1971) summarizes much of the work done in the Central Great Plains.

Numerous radiocarbon dates from southern Saskatchewan sites, and especially those obtained from wood samples rather than on sediments containing carbonates which may lead to anomalous ages, show that forested areas existed, with some fluctuations in tree abundance, from at least 11,700 years B.P. (S-183, 11,700 ± 300, Parizek, 1964) until about 10,000 years B.P. or slightly less (S-41, 10,050 + 300, Kupsch, 1960). As Ritchie (1966) has pointed out, little is known in detail of the vegetation that immediately followed recession of the ice and, as modern analogues of the early spruce pollen-dominated assemblages have not been found among contemporary vegetation communities, definite reconstructions of late-glacial vegetation cannot be made.

Study of fossil molluscs from a similar site along the Missouri Coteau in North Dakota led Tuthill *et al.* (1964) to conclude that, despite the fact that the molluscs occupied an ice-walled lake formed on stagnant glacier ice, the climate was mild and more humid than the present.

From his studies of freshwater ostracods, Delorme (1965) concluded that a warming trend followed glacial retreat from southern Saskatchewan. The climate cooled again, possibly as a result of glacial readvance before another warming trend began. This led to "a prolonged time of widespread aridity and drought which began about 8500 years ago". Following this, the climate cooled and precipitation again increased somewhat.

A decline in the relative abundance of arboreal pollen in the Herbert site (Kupsch, 1960) and Scrimbit Farm site (Terasmae, unpubl.) pollen diagrams plus the assemblages in the Crestwynd diagram (Ritchie, 1966) indicate that, shortly after 10,000 years B.P., prairie conditions prevailed along the Missouri Coteau. The Clearwater Lake diagram shows that these conditions endured to the present. A less humid and warmer climate was probably the cause of the shift to herbaceous vegetation. Undoubtedly further climatic changes occurred in the last 9000 years which were reflected in the vegetation, but more work is required before the details of these floristic changes can be determined.

As the three most northerly pollen diagrams show, the boreal forest, if such it was, followed the retreating ice. Evidence of a zone of tundra-type vegetation preceding the spruce invasion is meagre but the abundance of willow and herb pollen at the base of the Cycloid Lake diagram may suggest this. The spruce zone was widespread throughout the western interior of Canada, as seen in several diagrams from Manitoba (Ritchie, 1964, 1966; Ritchie and Lichti-Federovich, 1968). An absolute frequency pollen diagram from the Riding Mountain area of Manitoba (Ritchie, 1969) vividly portrays the spruce zone and shows no evidence of a preceding treeless tundra zone. A diagram from central Alberta (Lichti-Federovich, 1970) also shows a spruce zone at the base, but there a zone with abundant pollen of Populus, shrubs and herbs occurs below.

An invasion of grassland elements following the decline of spruce is seen in the abundant herb pollen types from Lake A near Prince Albert. The pollen assemblages in this zone compare with those found in modern treeless grassland areas and, with the possible exception of aspen, the Prince Albert area was open grassland. Delorme's ostracod studies from nearby Sturgeon Lake (Delorme, 1965) confirm this conclusion. At Lake B herbaceous pollen types also increase considerably following the spruce maximum but not enough to indicate open grassland conditions. Comparison with contemporary spectra suggests a parkland type of vegetation similar to that existing in the modern aspen parkland. No evidence of grassland vegetation closer to the site can be seen in the pollen diagram from Cycloid Lake where birch increased strongly following the spruce zone and jack pine invaded the area about 6000 years B.P. The date on the jack pine incursion provides interesting additional information to the discussion of the migration of jack pine by Yeatman (1967) and Wright (1968).

Forest conditions then returned to the Lake A and B areas and a mixed forest similar to the present gradually developed, probably as a result of cooling and increased precipitation. At Cycloid Lake the coniferous forest prevailed with only minor changes in the ratios of various species. The time of the reinvasion of the grassland area by forests is not known in central Saskatchewan for lack of radiocarbon dates. In the Riding Mountain area of Manitoba (Ritchie, 1969) the forest resurgence seems to have occurred about 2500 years B.P.

The conclusions of Bryson and Wendland (1967) of a southwestward shift of the boreal forest about 3500 years B.P. are in conflict but more dates are required before definite conclusions can be drawn about the time the present forest types developed.

More detailed pollen analyses using the absolute frequency method and more radiocarbon dates on critical changes in pollen assemblages are required before the vegetational and climatic history of the Canadian Western Interior are fully known.

ACKNOWLEDGMENTS

The author is indebted to T.W. Anderson and J. Fathers for help with field work and to S. Federovich for critically reading the manuscript.

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