Géographie physique et Quaternaire

Aspects of the Postglacial Climate of Alberta: Calibration of the Pollen Record
Quelques aspects du climat postglaciaire en Alberta : étalonnage des données polliniques
Aspekte des postglazialen Klimas von Alberta: Kalibrierung der Pollen-Belege

Robert E. Vance

Volume 40, numéro 2, 1986

URI : https://id.erudit.org/iderudit/032635ar
DOI : https://doi.org/10.7202/032635ar

Aller au sommaire du numéro

Éditeur(s)

Les Presses de l'Université de Montréal

ISSN

0705-7199 (imprimé)
1492-143X (numérique)

Découvrir la revue

Citer cet article

Vance, R. E. (1986). Aspects of the Postglacial Climate of Alberta: Calibration of the Pollen Record. *Géographie physique et Quaternaire*, *40*(2), 153–160. https://doi.org/10.7202/032635ar

Résumé de l'article

La reconstitution du climat postglaciaire de l'Alberta présentée ici est fondée sur les études palynologiques portant sur l'Alberta et sur l'application d'équations d'étalonnage aux données polliniques du centre de l'Alberta. Les études palynologiques régionales démontrent que la végétation tardiglaciaire, dominée par des taxons non arboréens, et à l'occasion par Populus, a été remplacée par des associations dominées par Picea entre 12 000 et 10 000 BP. Au centre de l'Alberta, l'augmentation de la représentation du pollen d'herbacées laissent croire que la prairie était établie au nord de sa position actuelle du début jusqu'au milieu de l'Holocène. Dès 3500 BP, la limite de la prairie était déjà plus méridionale. Peu de changements se sont manifestés depuis 3500 ans. Les équations d'étalonnage, faites à partir des données polliniques et climatiques actuelles provenant de la partie ouest de l'intérieur du Canada et appliquées à un inventaire portant sur 11 400 ans, laissent croire qu'au milieu de l'Holocène la température au cours de la saison végétative était de 1,5^{o}C supérieure à maintenant et que les précipitations durant cette saison étaient inférieures de 50 mm à maintenant.

Géographie physique et Quaternaire, 1986, vol. XL, n° 2, p. 153-160, 6 fig., 3 tabl.

ASPECTS OF THE POSTGLACIAL CLIMATE OF ALBERTA: CALIBRATION OF THE POLLEN RECORD*

Robert E. VANCE, Department of Biological Sciences, Simon Fraser University, Burnaby, British Columbia V5A 1S6.

ABSTRACT This reconstruction of the postglacial climate of Alberta is based on a review of pollen studies within the province and the application of calibration equations to a pollen record from central Alberta. Regional palynological studies indicate that the late glacial vegetation, dominated by nonarboreal taxa and, on occasion, *Populus*, was replaced by a *Picea* dominated assemblage between 12,000 and 10,000 BP. In central Alberta, increased herbaceous pollen representation suggests that grassland was established north of its current position in early to middle Holocene time. By 3500 BP, the grassland boundary had retreated southward. Little vegetational change is evident during the last 3500 years. Calibration equations, derived from modern pollen and climatic data in the western interior of Canada and applied to an 11,400 year pollen record, suggest growing season temperature was 1.5°C greater than at present while growing season precipitation was 50 mm below current values during the middle Holocene.

RÉSUMÉ *Quelques aspects du climat postglaciaire en Alberta: étalonnage des données polliniques*. La reconstitution du climat postglaciaire de l'Alberta présentée ici est fondée sur les études palynologiques portant sur l'Alberta et sur l'application d'équations d'étalonnage aux données polliniques du centre de l'Alberta. Les études palynologiques régionales démontrent que la végétation tardiglaciaire, dominée par des taxons non arboréens, et à l'occasion par *Populus*, a été remplacée par des associations dominées par *Picea* entre 12 000 et 10 000 BP. Au centre de l'Alberta, l'augmentation de la représentation du pollen d'herbacées laissent croire que la prairie était établie au nord de sa position actuelle du début jusqu'au milieu de l'Holocène. Dès 3500 BP, la limite de la prairie était déjà plus méridionale. Peu de changements se sont manifestés depuis 3500 ans. Les équations d'étalonnage, faites à partir des données polliniques et climatiques actuelles provenant de la partie ouest de l'intérieur du Canada et appliquées à un inventaire portant sur 11 400 ans, laissent croire qu'au milieu de l'Holocène la température au cours de la saison végétative était de 1,5°C supérieure à maintenant et que les précipitations durant cette saison étaient inférieures de 50 mm à maintenant.

ZUSAMMENFASSUNG *Aspekte des postglazialen Klimas von Alberta: Kalibrierung der Pollen-Belege*. Diese Rekonstruktion des postglazialen Klimas von Alberta beruht auf einer Übersicht über die Pollen-Studien in der Provinz und der Anwendung der Kalibrierungs-Gleichungen auf die Pollen-Belege von Zentral-Alberta. Regionale palynologische Studien zeigen, daβ die spätglaziale Vegetation, welche durch nichtbaumartige Taxa und gelegentlich durch *Populus* beherrscht war, zwischen 12,000 und 10,000 v.u.Z. durch eine von *Picea* beherrschte Ansammlung ersetzt wurde. In Zentral-Alberta läβt zunehmendes pflanzliches Pollen-Vorkommen vermuten, daβ Grasland in der Zeit des frühen bis mittleren Holozän nördlich seiner jetzigen Position vorhanden war. Um 3500 v.u.Z. war die Grasland-Grenze südwärts zurückgewichen. Während der letzten 3500 Jahre sind wenige Wechsel in der Vegetation aufgetreten. Die Kalibrierungs-Gleichungen, die aus modernen Pollen- und Klima-Daten im inneren Westen von Kanada gewonnen wurden und auf einen 11,400 Jahre alten Pollen-Beleg angewendet werden, lassen vermuten, daβ im mittleren Holozän die Temperatur der Wachstumszeit um 1.5°C höher war als heute, während der Niederschlag in der Wachstumszeit um 50 mm unter den heutigen Werten lag.

---

* Contribution du premier symposium de la CANQUA, sous la direction de René W. Barendregt

INTRODUCTION

During the last decade a number of paleoecological studies have been undertaken in Alberta. A survey of the fossil pollen studies in the province indicates that, in general, a four phase sequence of pollen assemblages characterizes the postglacial period. The widespread occurrence and consistency of these pollen assemblages implies that regional vegetational changes have occurred. These adjustments may have been stimulated by climatic change. The purpose of this paper is to outline a general sequence of postglacial pollen assemblages, offer an interpretation (both in terms of vegetation and climate) of these assemblages, and quantify aspects of climatic interpretations of the pollen record.

SETTING

Alberta lies on the eastern flank of the Rocky Mountains. The vegetation of the province may be divided into four major zones (Fig. 1). In the southeast lies the flat, treeless grassland. To the north aspen parkland, a mosaic of *Populus* groves and grassland, lies on rolling topography. It separates the grassland from the closed coniferous forests of the boreal and montane zones.

The general south to north cline of grassland to forest is largely the product of a temperature and precipitation gradient. Warmest, driest conditions occur in the south while a cooler and wetter climate prevails in the north, and at higher elevations in the west. Growing season (May, June, July, and August) temperature averages approximately 16°C in southern Alberta, 14°C in central regions, and 12°C in the north; while growing season precipitation is approximately 200 mm in the south, 275 mm in central Alberta, and 300 mm in the north (Canadian Climatic Normals 1951-1980).

Although elevation is the main determinant of the montane climate, air mass characteristics and location control, in a large way, the distribution of vegetation in the remaining ecological zones. The southern grassland is dominated by Pacific air virtually year-round. This relatively mild air dries as it descends off the Rocky Mountains. Its frequent appearance in winter is responsible for the large number of chinooks in southern Alberta (HARE and THOMAS, 1979). In the north, the Arctic air mass dominates. Short-term observation suggests that the mean winter position of its southern boundary corresponds to the northern limit of the aspen parkland; while in summer, the mean position of the arctic air mass typically moves to the north of the boreal forest (BRYSON, 1966). The combination of the westerlies descending off the Rocky Mountains and the mixing of Pacific and Arctic air results in frequent storms, known as Alberta lows (CALDER, 1974; KENDREW and CURRIE, 1951). Mixing of these air masses most frequently occurs in Alberta over the parkland and boreal forest. This interaction produces greater precipitation in central and northern regions, compared to southern Alberta.

THE POLLEN RECORD

A total of 33 radiocarbon dated sites in Alberta are utilized in this review (Fig. 1, Table I). Although many sites in the aspen parkland do not span the postglacial, a number of complete sections in the montane and boreal forest regions allow the development of a generalized late Quaternary vegetational history for the province. Due to the paucity of complete postglacial sections in the aspen parkland and the absence of pollen stratigraphic evidence in the grassland, vegetational change in these regions must be inferred from sites in adjacent regions.

Four main pollen zones are typically encountered in complete postglacial sections. The earliest pollen zone has a significant non-arboreal component, consisting mainly of Gramineae, Cyperaceae, and *Artemisia*. *Populus* appears in varying amounts and, on occasion, dominates. As no modern analogue of this non-arboreal/*Populus* pollen assemblage has been discovered, interpretations are varied and equivocal. Tundra (HOLLOWAY *et al.*, 1981) tundra-like (MOTT and JACKSON, 1982; SCHWEGER *et al.*, 1981), and a zone with southern grassland-parkland affinities (WHITE, 1983), are descriptions that have been used to characterize this assemblage. These interpretations are based principally on the presence of indicator taxa. Since most of the non-arboreal pollen types found in this zone cannot be identified to the species level, and many of the taxa are found today in both tundra and grassland, pollen analysis is unable to provide unequivocal interpretations at present.

The early postglacial vegetation, with the exception of sites in the "ice-free corridor" (RUTTER, 1980), is short-lived. It is replaced by a *Picea* dominated pollen assemblage that has no known modern analogue (as it contains no *Pinus* or *Alnus*), and often contains significant amounts of *Betula*. The pollen stratigraphy of a site in southern Saskatchewan (RITCHIE and DEVRIES 1964) suggests *Picea* may have been present

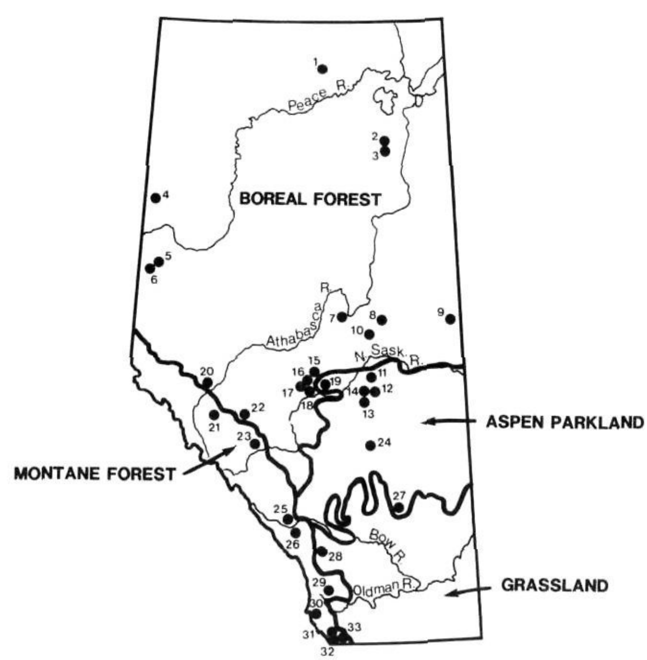

FIGURE 1. Alberta vegetation zones, study sites.
Carte des zones de végétation de l'Alberta et des sites étudiés.

TABLE I

Alberta study sites

1.	Wild Spear Lake	MacDONALD (1984)
2.	Eaglenest Lake	VANCE (1986)
3.	Clear Lake	VANCE (unpublished)
4.	Lone Fox Lake	MacDONALD (1984)
5.	Boone Lake	WHITE (1983)
6.	Spring Lake	WHITE (1983)
7.	Baptiste Lake	HICKMAN *et al.* (1979)
8.	Lofty Lake	LICHTI-FEDEROVICH (1970)
9.	Moore Lake	SCHWEGER *et al.* (1981)
10.	Alpen Siding	LICHTI-FEDEROVICH (1972)
11.	E. I. Pond	VANCE *et al.* (1983)
12.	Hastings Lake	VANCE *et al.* (1983)
		FORBES & HICKMAN (1981)
13.	Joseph Lake	VANCE (unpublished)
14.	Cooking Lake	HICKMAN (unpublished)
15.	Lac Ste. Anne	FORBES & HICKMAN (1978)
		FORBES (unpublished)
16.	Lake Isle	HICKMAN & KLARER (1981)
		SCHWEGER & HABGOOD (unpublished)
17.	Wabamun Lake	HOLLOWAY *et al.* (1981)
		HICKMAN *et al.* (1984)
18.	Muskrat Bog	SCHWEGER & HABGOOD (unpublished)
19.	Smallboy Lake	VANCE *et al.* (1983)
20.	Gregg Lake	SCHWEGER & HABGOOD (unpublished)
21.	Mary Gregg Lake	BOMBIN (1982)
22.	Fairfax Lake	SCHWEGER *et al.* (1981)
23.	Goldeye Lake	SCHWEGER & HICKMAN (unpublished)
24.	Buffalo Lake	HICKMAN *et al.* (1982)
25.	Yamnuska Bog	MacDONALD (1982)
26.	Wedge Lake	MacDONALD (1982)
27.	Little Fish Lake	KROKER (1979)
28.	Chalmers Bog	MOTT & JACKSON (1982)
29.	Callum Bog	ALLEY (1972)
30.	Crowsnest Lake	DRIVER (1978)
31.	Goat Lake	BUJAK (1974)
32.	Lost Lake	BUJAK (1974)
33.	Linnet Lake	CHRISTIANSEN & HILLS (1971)

in southern Alberta as early as 11,650 BP. *Picea* appeared in central Alberta 11,400 BP (LICHTI-FEDEROVICH, 1970; SCHWEGER *et al.*, 1981), and arrived in northern Alberta about 10,750 BP (VANCE, 1986). *Pinus* and *Alnus* first appeared in central Alberta about 7500 BP (LICHTI-FEDEROVICH, 1970).

Fossil pollen and diatom studies, combined with sediment chemistry analyses and charcoal counts, indicate that in central Alberta grassland expanded north of its current northern limit, lake levels dropped, and fire frequency increased about 9000 BP (SCHWEGER *et al.*, 1981). These conditions persisted until 6000 BP. This is considered to be the most severe postglacial drought in central Alberta (*ibid*). Fossil pollen and charcoal evidence from sites southeast of Edmonton indicates less severe drought conditions persisted until 4000 BP (VANCE *et al.*, 1983).

Fossil pollen analyses from sites further north in the boreal forest show no clear-cut evidence of a Holocene warm period (MacDONALD, 1984; VANCE, 1986). Along the eastern slopes, increased *Pinus* representation (WHITE, 1983) and an increased frequency of *Pinus* relative to *Picea* and *Abies* (MacDONALD, 1982), about 7500 BP, have been interpreted as representing a response to more frequent fires, a condition that is thought to have been stimulated by a warmer and drier climate.

Fossil pollen, diatom, and charcoal stratigraphy, combined with a suite of basal radiocarbon dates from sedimentary basins in central Alberta, indicate that lake and bog formation was initiated in this region about 4000 BP, likely a consequence of the onset of a cooler and moister climatic regime (SCHWEGER *et al.*, 1981; VANCE *et al.*, 1983). By approximately 3500 BP, paleoecological records indicate that modern vegetation patterns were established throughout the province. Little vegetational change has occurred to the present, suggesting modern climatic conditions have persisted over the last 3500 years.

DERIVATION OF CALIBRATION EQUATIONS

Fossil pollen assemblages are an expression of vegetational change. Vegetational changes are influenced by climatic events. Calibration equations have been utilized in other areas of North America to quantitatively assess paleoclimatic parameters of the pollen record, following the initial effort of WEBB and BRYSON (1972), but have been used infrequently in the western interior of Canada (BUCHNER, 1980; RITCHIE, 1983). As regional trends in vegetational change appear in pollen records from Alberta, calibration equations may provide insight into paleoclimatic events.

The basic assumptions involved in the application of calibration equations to pollen records are that climate is the ultimate cause of changes in the pollen record, that vegetation has responded in a similar way to climate over time, and that a linear relationship exists between pollen and climatic variables (WEBB and BRYSON, 1972). These assumptions may be questioned. Certainly other factors independent of climate, for example migration, cause changes in pollen records (BIRKS, 1981). In addition, all pollen taxa do not exhibit a linear relationship to the climatic parameter under investigation (RITCHIE, 1983). Despite these limitations, calibration equations were developed to obtain preliminary estimates of past climatic events in Alberta. Clearly, given the above limitations, the derived estimates can only be considered exploratory efforts.

Calibration equations for estimating growing season temperature and precipitation were developed following the methods outlined by ARIGO *et al.* (1982). Modern pollen samples were limited to those from lakes that are in close proximity to meteorological stations with long-term records. In this way, the most accurate climatic parameters were applied to the modern pollen assemblages. Moreover, all the modern pollen samples used were derived from lake sediment, a context analogous to the fossil pollen record. A total of 39 sites were utilized in this study (Fig. 2, Table II). Significant gaps in this large geographical area are apparent, but the range of pollen and climatic variability approached the postglacial variability, and the coverage was deemed adequate for this preliminary investigation.

TABLE II

Modern surface sample locations

1.	Crowsnest Lake	DRIVER (1978)
2.	Shanks Lake	VANCE (unpublished)
3.	Tyrrell Lake	VANCE (unpublished)
4.	Chappice Lake	VANCE (unpublished)
5.	Buffalo Lake	HICKMAN *et al.* (1982)
6.	Hastings Lake	VANCE *et al.* (1983)
7.	Lac Ste. Anne	FORBES (unpublished)
8.	Fairfax Lake	SCHWEGER *et al.* (1981)
9.	Baptiste Lake	HICKMAN *et al.* (1979)
10.	Lofty Lake	LICHTI-FEDEROVICH (1970)
11.	Moore Lake	SCHWEGER *et al.* (1981)
12.	Boone Lake	WHITE *et al.* (1983)
13.	Eaglenest Lake	VANCE (1986)
14.	Clearwater Lake	MOTT (1972)
15.	Wakaw Lake	MOTT (1969)
16.	Lake A	MOTT (1972)
17.	Lake B	MOTT (1972)
18.	Cycloid Lake	MOTT (1972)
19.	Catherine Lake	LICHTI-FEDEROVICH & RITCHIE (1965)
20.	Moon Lake	LICHTI-FEDEROVICH & RITCHIE (1965)
21.	Peace Lake	LICHTI-FEDEROVICH & RITCHIE (1965)
22.	North Shoal Lake	LICHTI-FEDEROVICH & RITCHIE (1965)
23.	Oak Lake	LICHTI-FEDEROVICH & RITCHIE (1965)
24.	Marchand Lake	LICHTI-FEDEROVICH & RITCHIE (1965)
25.	Wet Lake	LICHTI-FEDEROVICH & RITCHIE (1965)
26.	Falcon Lake	LICHTI-FEDEROVICH & RITCHIE (1965)
27.	V Lake	LICHTI-FEDEROVICH & RITCHIE (1965)
28.	W lake	LICHTI-FEDEROVICH & RITCHIE (1965)
29.	Lake Clementi	LICHTI-FEDEROVICH & RITCHIE (1965)
30.	Site 10	RITCHIE (1974)
31.	Site 28	RITCHIE (1974)
32.	Site 34	RITCHIE (1974)
33.	Hanging Lake	CWYNAR (1982)
34.	Site 1	LICHTI-FEDEROVICH & RITCHIE (1968)
35.	Site 8	LICHTI-FEDEROVICH & RITCHIE (1968)
36.	Site 19	LICHTI-FEDEROVICH & RITCHIE (1968)
37.	Site 23	LICHTI-FEDEROVICH & RITCHIE (1968)
38.	Site 116	LICHTI-FEDEROVICH & RITCHIE (1968)
39.	Site 36	LICHTI-FEDEROVICH & RITCHIE (1968)

Of the 34 pollen taxa present in the modern surface samples, 15 meet the criteria of mean representation greater than 1 %, or maximum value greater than 5 % (ARIGO *et al.*, 1982). These taxa are *Populus, Pinus, Picea, Quercus, Betula, Salix, Alnus, Artemisia*, Tubuliflorae, *Ambrosia*, Gramineae, Chenopodiaceae, Ericaceae, *Rumex*, and Cyperaceae. *Populus* was excluded from further analysis because of its variable preservation (MOTT, 1978). *Quercus* was eliminated because it is not native to Alberta (MOSS, 1983).

Once the pollen taxa suitable for analysis were chosen, the following steps were undertaken (as outlined in ARIGO *et al.*, 1982). Scattergrams of pollen percentage vs. growing season temperature and precipitation were generated to assess the relationship between the variables. Transformations were performed in an attempt to produce better linear relationships. No outlier sites were removed. Forward-selection stepwise multiple regression was followed by selection of the appropriate

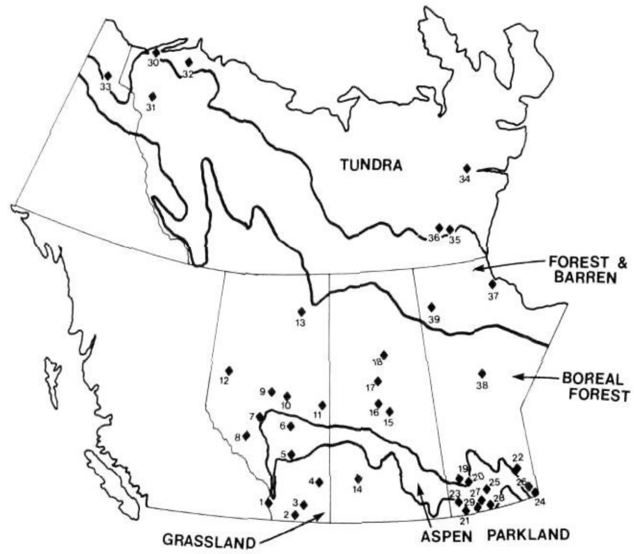

FIGURE 2. Location of modern surface sample collections.
Carte de localisation des collections des échantillons de surface.

equation based on an inspection of the adjusted R^2 and standard errors.

RESULTS OF REGRESSION

The Lofty Lake pollen record (LICHTI-FEDEROVICH, 1970) was chosen for calibration for three reasons. First, it is a securely dated, complete postglacial record. Second, it is representative of the four phase sequence of pollen zones outlined in an earlier section. Third, it is located slightly north of the aspen parkland (Fig. 1), a region currently lying in the zone of winter interaction of the Arctic and Pacific air masses (BRYSON, 1966). As such, it is situated in an area that should be more sensitive to climatic change than sites further removed from transition zones (BRYSON and WENDLAND, 1967).

A summary of the Lofty Lake pollen diagram, recalculated to include only the 13 pollen taxa considered in the multiple regression procedure (Fig. 3), illustrates the general sequence of vegetational change characteristic of postglacial pollen records in Alberta. An early non-arboreal/*Populus* zone (*Populus* is not included in Figure 3, but it is a major component of zone L1 in the original pollen diagram) is followed by *Picea* (L2) and *Betula* (L3) dominated assemblages. Herbaceous taxa show increased representation in the middle Holocene (L4), indicative of grassland expansion. By approximately 3500 BP, pollen spectra analogous to the modern pollen assemblage appear and remain unchanged to the present, indicating modern vegetation has prevailed since that time.

Postglacial growing season temperatures were estimated by applying the regression equation (Table III) to the Lofty Lake pollen data. This equation estimates present growing season temperature within 0.2°C of the actual value (13.8°C). Although the data points display considerable variability (Fig. 4), trends are apparent. The smoothed curve shifts postglacial

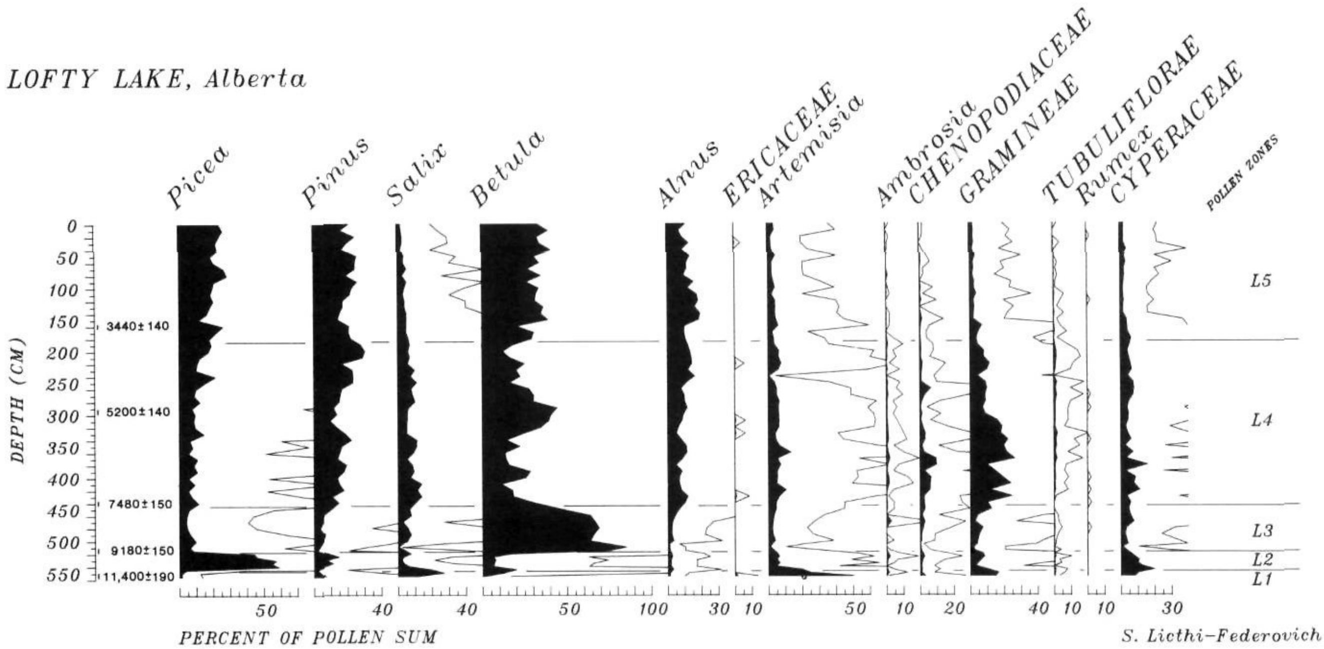

FIGURE 3. Lofty Lake percentage pollen diagram, modified to include only the taxa used in the regression analysis.

Diagramme des pourcentages polliniques, légèrement modifié en vue d'inclure les taxons utilisés pour l'analyse de régression.

TABLE III

Calibration equations

GROWING SEASON TEMPERATURE

TRANSFORMATIONS: Log 10 *Pinus, Picea, Salix, Artemisia*, Tubuliflorae, Gramineae; Ericaceae$^{.25}$; Chenopodiaceae$^{.25}$; *Rumex*$^{.33}$; *Ambrosia*$^{.50}$.

REGRESSION EQUATION: Growing Season Temperature = 12.41 − 4.38* Ericaceae$^{.25}$ + 1.29* Chenopodiaceae$^{.25}$ − 2.47* *Rumex*$^{.33}$ + 0.89* *Ambrosia*$^{.50}$.

Std. error = 1.27, R^2 = 0.91

GROWING SEASON PRECIPITATION

TRANSFORMATIONS: Log 10 *Pinus, Picea, Salix, Artemisia*, Tubuliflorae; Ericaceae$^{.25}$; Chenopodiaceae$^{.25}$; *Rumex*$^{.30}$.

REGRESSION EQUATION: Growing Season Precipitation = 231.63 − 104.32*Ericaceae$^{.25}$ + 52.34*Log 10 *Picea* + 10.97**Ambrosia* − *Rumex*$^{.33}$ − 31.96*Chenopodiacea$^{.25}$ + 32.53*Log 10 *Salix* − 1.68**Alnus* + 24.95*Log 10 Tubuliflorae.

Std. error = 32.12, R^2 = 0.86.

temperature estimates away from the current value, but a series of relative temperature changes are evident. The smoothed curve indicates an abrupt temperature rise occurred in the late glacial. From approximately 10,000 to 6000 BP, growing season temperature was about 1.5°C warmer than at present. From 6000 to 3000 BP, growing season temperature remained above current values, but was reduced from the earlier maximum. Beginning about 3000 BP, growing season temperature declined and attained its present value by approximately 1000 BP.

The regression equation derived for growing season precipitation (Table III) estimates a current value some 70 mm below the actual value (306 mm). Postglacial precipitation estimates, presented as a smoothed curve (Fig. 5), suggest precipitation rose rapidly in the late glacial and attained maximum values about 10,000 BP. Growing season precipitation then dropped below current levels. Minimum values, some 50 mm below those at present, were attained between 8000 and 6000 BP. Beginning about 6000 BP, growing season precipitation rose, reaching current levels by approximately 4000 BP. Little change occurred from 4000 BP to the present.

INTERPRETATION

Temperature and precipitation trends, estimated from regression equations, provide an approximation of postglacial climatic conditions in central Alberta. They suggest that from early to middle Holocene time (approximately 9000 to 4000 BP) conditions were warmer and drier than at present. Warmest and driest conditions occurred between 9000 and 6000 BP. This is in accord with the Holocene drought period delineated by SCHWEGER *et al.* (1981) and VANCE *et al.* (1983), and differs from the original interpretation of the Lofty Lake record only to the extent that warmer and drier conditions appear earlier than 7500 BP, the date LICHTI-FEDEROVICH (1970) proposed to mark grassland expansion. Growing season precipitation appears to have remained relatively stable over the last 4000 years. Growing season temperature remained above normal until 1000 BP, although it had begun to decline about 3000 BP.

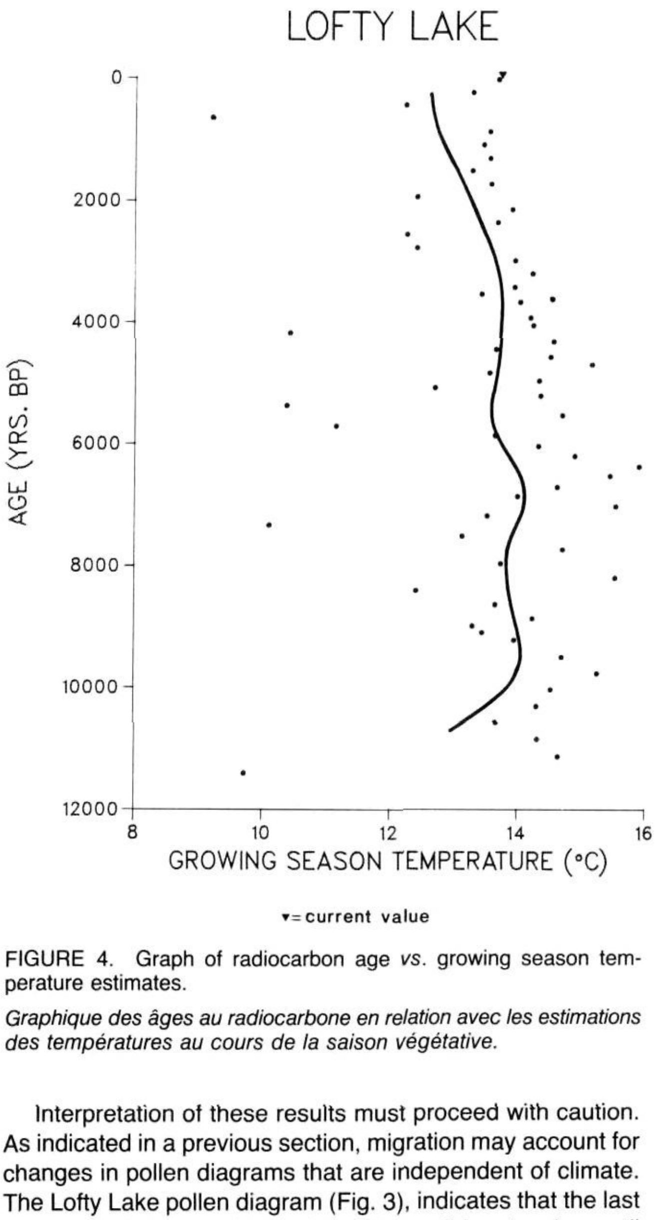

FIGURE 4. Graph of radiocarbon age *vs.* growing season temperature estimates.

Graphique des âges au radiocarbone en relation avec les estimations des températures au cours de la saison végétative.

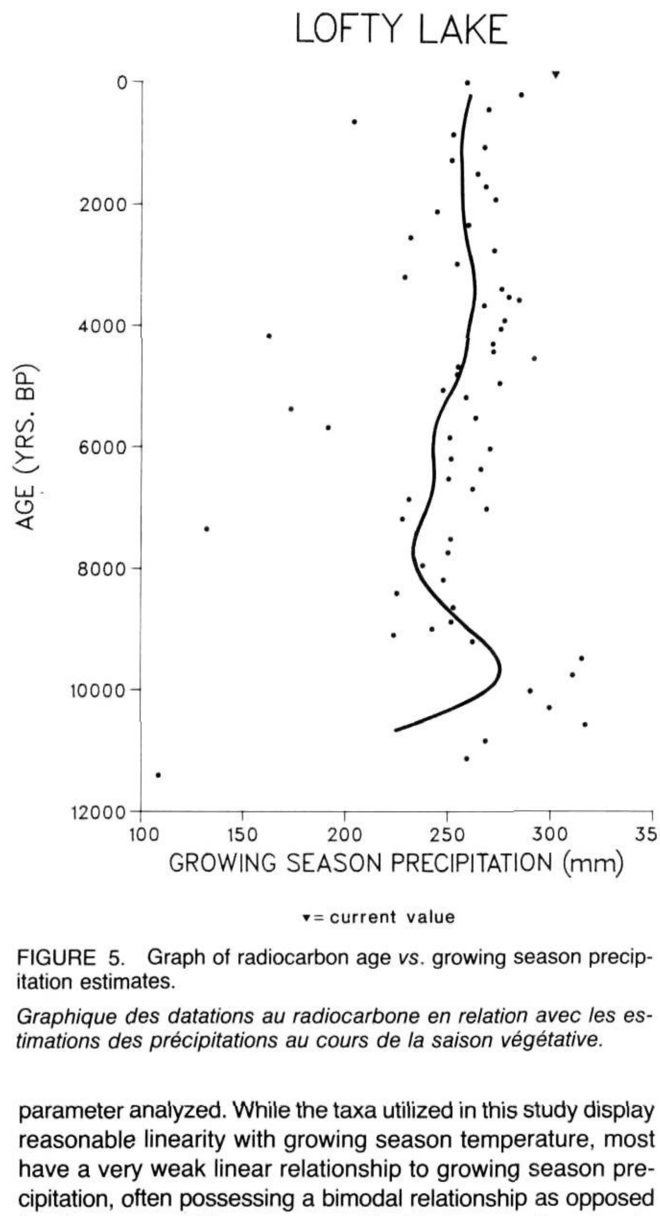

FIGURE 5. Graph of radiocarbon age *vs.* growing season precipitation estimates.

Graphique des datations au radiocarbone en relation avec les estimations des précipitations au cours de la saison végétative.

Interpretation of these results must proceed with caution. As indicated in a previous section, migration may account for changes in pollen diagrams that are independent of climate. The Lofty Lake pollen diagram (Fig. 3), indicates that the last taxon to migrate to the region, *Pinus*, did not arrive until 7500 BP. Earlier migrations of *Picea*, *Betula*, and *Alnus* stimulated major changes in early Holocene pollen assemblages. Thus, regression estimates prior to 7500 BP may be a reflection of plant migrations, rather than climate. For example, abrupt changes in early postglacial growing season precipitation estimates (Fig. 5) may have resulted from the migration of *Picea* to the region, an event that likely had little to do with precipitation changes.

In addition, no modern analogues of the early pollen assemblages at Lofty Lake (L1, L2, and L3) have been discovered. The high percentages of *Artemisia, Picea*, and *Betula*, successively in each of these zones, are not matched in the modern surface sample set used to derive the calibration equations. This lack of modern analogues is further warning that climatic estimates prior to 7500 BP are suspect.

A further note of caution involves the assumption that pollen abundances show a linear relationship to the climatic parameter analyzed. While the taxa utilized in this study display reasonable linearity with growing season temperature, most have a very weak linear relationship to growing season precipitation, often possessing a bimodal relationship as opposed to a linear one. This may account for the inaccurate estimate of modern growing season precipitation at Lofty Lake.

Bearing these limitations in mind, it is possible to suggest causes for the reconstructed changes in postglacial precipitation and temperature. Aspects of late glacial and early Holocene boundary conditions suggest a relatively mild and dry climate may have prevailed over recently deglaciated areas of Alberta. Calculations based on the Milankovitch theory (VERNEKER, 1972) reveal maximum summer insolation occurred in northern latitudes about 10,000 BP. Continental ice sheets, although reduced from their maximum size, likely remained a significant barrier to atmospheric circulation, perhaps increasing the frequency of blocking over recently deglaciated areas of the western interior of Canada (VANCE, in press). This would have resulted in summers warmer than at present and below normal precipitation. With the exception of the abrupt peak in growing season precipitation, about 10,000 BP (which may be the result of the impact of the *Picea* migration on the pollen record), the early Holocene climatic estimates presented here (Fig. 4 and Fig. 5) lend support to this scenario. In this climatic setting, the early postglacial vegetation may have been more akin to modern grassland than modern tundra, and early *Picea* forests may have had a more open canopy than is characteristic of the boreal forest today.

By 7500 BP the ice sheets were likely too small to influence atmospheric circulation. The middle Holocene (7500-4000 BP) drought period in central Alberta may have been caused by a slight northward displacement of the current position of the Arctic air mass, an event most likely associated with the more frequent occurrence of Pacific air documented in the middle west of the United States at this time (WRIGHT, 1983). A vigorous westerly flow may have pushed warm, dry Pacific air further west in the central United States, as well as forcing the Arctic air mass to the north of its current position. These shifts in air mass positions would have increased the residence time of Pacific air over central regions of the province, creating warmer conditions of the magnitude indicated by the calibration equations. Conditions drier than at present in central Alberta may also have been a product of a northward shift in the Arctic air mass, as the zone of interaction between Pacific and Arctic air would have been shifted north of its current position.

A southward shift in the mean position of the Arctic air mass, about 4000 BP, would have produced climatic conditions similar to those at present. The persistence of warmer than at present temperatures, albeit declining, from 4000 to 1000 BP is difficult to explain in this context, but may be related to instability in air mass location during the transition from middle Holocene to current conditions. More frequent southward excursions of Arctic air about 4000 BP may account for increased precipitation. However, Pacific air may have continued to reside over central Alberta for longer periods than it does today until about 3000 BP. Residence time then decreased until about 1000 BP, when current residence times were achieved.

It is clear that the calibration equations presented here provide only tentative estimates of postglacial climatic conditions. Plant migration and the presence of pollen assemblages with no modern analogues, prior to 7500 BP, cloud the climatic signal. From 7500 BP to the present, climatic estimates are likely to have better resolution. These estimates may be improved by a more complete network of modern surface samples. Moreover, a method of measuring effective precipitation, as opposed to simply precipitation, may improve the linearity of pollen-precipitation relationships, thereby improving the accuracy of postglacial precipitation estimates.

CONCLUSION

Palynological evidence in Alberta suggests significant climatic changes have occurred in postglacial time. Late glacial assemblages and early Holocene *Picea* zones, pollen assemblages with no known modern analogues, may have existed under a climate warmer and drier than at present, a result of the influence of continental ice and variations in solar insolation. Estimates of late glacial and early Holocene climatic parameters based on calibration equations support this reconstruction, but are equivocal as they are hampered by the presence of pollen assemblages with no modern analogues and changes in the pollen record brought about by plant migrations. Middle Holocene climates, with growing season temperature as much as 1.5°C warmer and growing season precipitation 50 mm less than at present, were likely the result of a northward shift in the mean position of air masses over the province. The vegetation has remained relatively stable since about 3500 BP, and essentially modern climatic conditions have prevailed over the last 3000 to 4000 years.

ACKNOWLEDGEMENTS

Special thanks go to I. Walker for advice on the calibration procedures. R. Mathewes, G. Quickfall, I. Walker, C. Schweger and an anonymous reviewer provided comments on earlier drafts of this manuscript. Their help is gratefully acknowledged.

REFERENCES

ALLEY, N. F. (1972): *The Quaternary History of Part of the Rocky Mountains, Foothills, Plains, and Western Porcupine Hills, Southwestern Alberta*, Calgary, Ph.D. thesis, 201 p.

ARIGO, R., HOWE, S. E., and WEBB, T. (1982): Computer programs for climatic calibration of pollen data, *in Palaeohydrological Changes in the Temperate Zone in the Last 15 000 Years Subproject B. Lake and Mire Environments*, Berglund, B. E. (ed.), Lund, Sweden, p. 79-109.

BIRKS, H. J. B. (1981): The use of pollen analysis in the reconstruction of past climates: a review, *in Climate and History*, Wigley, T. M. L., Ingram, M. J. and Farmer, G. (eds.), New York, Cambridge University Press, p. 111-138.

BOMBIN, E. R. (1982): *Holocene Paleolimnology of Mary Gregg Lake, Foothills of the Alberta Rocky Mountains, Canada*, Edmonton, M.Sc. thesis.

BRYSON, R. A. (1966): Air masses, streamlines, and the Boreal Forest, *Geographical Bulletin*, Vol. 8, p. 228-269.

BRYSON, R. A. and WENDLAND, W. M. (1967): Tentative climatic patterns for some late-glacial and post-glacial episodes in central North America, *in Life, Land, and Water, Lake Agassiz Region*, Mayer-Oakes, W. M. (ed.), Department of Anthropology, University of Manitoba, p. 271-298.

BUCHNER, A. P. (1980): *Cultural Responses to Altithermal (Atlantic) Climate Along the Eastern Margins of the North American Grasslands 5500 to 3000 B.C.*, Ottawa, Archaeological Survey of Canada, Paper No. 97.

BUJAK, C. A. (1974); *Recent Palynology of Goat Lake and Lost Lake, Waterton Lakes National Park*, Calgary, M.Sc. thesis.

CALDER, N. (1974): *The Weather Machine*, London, British Broadcasting Company, 143 p.

Canadian Climatic Normals Temperature and Precipitation Prairie Provinces 1951-1980, Ottawa, Canadian Climate Program, Environment Canada, Atmospheric Environment Service.

CHRISTIANSEN, O. A. and HILLS, L. V. (1971): *Palynologic and paleoclimatic interpretation of recent sediments, Waterton Lakes National Park, Alberta*, Report to National and Historic Parks Branch, Department of Indian Affairs and Northern Development, Ottawa, 14 p.

CWYNAR, L. C. (1982): A late-Quaternary vegetation history from Hanging Lake, northern Yukon, *Ecological Monographs*, Vol. 52, p. 1-24.

DRIVER, J. C. (1978): *Holocene Man and Environments in the Crowsnest Pass, Alberta*, Calgary, Ph.D. thesis, University of Calgary, 230 p.

FORBES, J. R. and HICKMAN, M. (1978): *The Environmental History of Lac Ste. Anne and its Basin*, Report submitted to Alberta Environment Pollution Control Division, Water Quality Control Branch, Edmonton, 30 p.

FORBES, J. R. and HICKMAN, M. (1981): Paleolimnology of two shallow lakes in central Alberta, Canada, *International Revue Der Gesamten Hydrobiologie*, Vol. 66, p. 863-888.

HARE, F. K. and THOMAS, M. K. (1979): *Climate Canada*, 2nd. edition, Toronto, John Wiley and Sons, 230 p.

HICKMAN, M., BOMBIN, E. and BOMBIN, M. (1982): *A Paleoenvironmental History Derived from a Core Taken from Buffalo Lake, Alberta*, Report prepared for Alberta Environment, Planning Division, 22 p.

HICKMAN, M., KLARER, D. M., SCHWEGER, C. and HABGOOD, T. (1979): *The Paleoenvironmental History of Baptiste Lake, Alberta*, Report submitted to Alberta Environment, Water Quality Section, 48 p.

HICKMAN, M. and KLARER, D. M. (1981): Paleolimnology of Lake Isle, Alberta (including sediment chemistry, pigments and diatom stratigraphy), *Archiv Fur Hydrolobiologie*, Vol. 91, p. 450-508.

HICKMAN, M., SCHWEGER, C. E., and HABGOOD, T. (1984): Lake Wabamun Alta.: a paleoenvironmental study, *Canadian Journal of Botany*, Vol. 62, p. 1438-1465.

HOLLOWAY, R. G., BRYANT, V. M., Jr., and VALASTRO, S. (1981): A 16,000 year pollen record from Lake Wabamun, Alberta, Canada, *Palynology*, Vol. 5, p. 195-207.

KENDREW, W. G. and CURRIE, B. W. (1955): *The Climate of Central Canada*, Ottawa, Queen's Printer, 194 p.

KROKER, S. (1979): *Late Holocene Paleoecology of the Hand Hills Region of Alberta: Implications for Archaeological Research*, Winnipeg, M. A. thesis.

LICHTI-FEDEROVICH, S. (1970): Pollen stratigraphy of a dated section of late Pleistocene lake sediment from central Alberta, *Canadian Journal of Earth Sciences*, Vol. 7, p. 939-944.

——— (1972): Pollen stratigraphy of a sediment core from Alpen Siding, *in Report of Activities, Part B. Geological Survey of Canada*, Paper 72-1B, p. 113-115.

LICHTI-FEDEROVICH, S. and RITCHIE, J. C. (1965): Contemporary pollen spectra in central Canada II. The forest-grassland transition in Manitoba, *Pollen et Spores*, Vol. 7, p. 63-87.

——— (1968): Recent pollen assemblages from the western interior of Canada, *Review of Palaeobotany and Palynology*, Vol. 7, p. 297-344.

MacDONALD, G. M. (1982): Late Quaternary paleoenvironments of the Morley Flats and Kananaskis Valley of southwestern Alberta, *Canadian Journal of Earth Sciences*, Vol. 19, p. 23-35.

——— (1984): *Postglacial Plant Migration and Vegetation Development in the Western Canadian Boreal Forest*, Toronto, Ph.D. thesis.

MOSS, E. H. (1983): *Flora of Alberta*, 2nd Edition, Revised by Packer, J. G., Toronto, University of Toronto Press, 687 p.

MOTT, R. J. (1969): *Palynological Studies in Central Saskatchewan: Contemporary Pollen Spectra from Surface Samples*, Ottawa, Geological Survey of Canada Paper 69-32, 13 p.

——— (1972): *Palynological Studies in Central Saskatchewan: Pollen Stratigraphy from Lake Sediment Sequences*, Ottawa, Geological Survey of Canada Paper 72-49, 18 p.

——— (1978): *Populus* in late-Pleistocene pollen spectra, *Canadian Journal of Botany*, Vol. 56, p. 1021-1031.

MOTT, R. J. and JACKSON, L. E., Jr. (1982): An 18000 year palynological record from the southern Alberta segment of the classical Wisconsinan "ice-free corridor", *Canadian Journal of Earth Sciences*, Vol. 19, p. 504-513.

RITCHIE, J. C. (1974): Modern pollen assemblages near the arctic tree line, Mackenzie Delta region, Northwest Territories, *Canadian Journal of Botany*, Vol. 52, p. 381-396.

——— (1983): The paleoecology of the central and northern parts of Glacial Lake Agassiz basin, *in Glacial Lake Agassiz*, Teller, J. T. and Clayton, L. (eds.), Toronto, University of Toronto Press, p. 157-170.

RITCHIE, J. C. and DEVRIES, B. (1964): Contributions to the Holocene palaeoecology of west central Canada. A late-glacial deposit from the Missouri Coteau, *Canadian Journal of Botany*, Vol. 42, p. 677-692.

RUTTER, N. W. (1980): Late Pleistocene history of the western Canadian ice-free corridor, *Canadian Journal of Anthropology*, Vol. 1, p. 1-10.

SCHWEGER, C. E., HABGOOD, T., and HICKMAN, M. (1981): Late glacial-Holocene climatic changes in Alberta. The record from lake sediment studies, *in The Impact of Climatic Fluctuations on Alberta's Resources and Environment*, Leggat, K. D. and Kotylak, J. T. (eds.), Edmonton, Atmospheric Environment Service, p. 47-59.

VANCE, R. E. (1986): Pollen stratigraphy of Eaglenest Lake, northeastern Alberta, *Canadian Journal of Earth Sciences*, Vol. 23, p. 11-20.

——— (in press): Meteorological records of historic droughts as climatic analogues for the Holocene, *in Proceedings of the 17th Chacmool Conference*, Calgary, The University of Calgary.

VANCE, R. E., EMERSON, D., and HABGOOD, T. (1983): A mid-Holocene record of vegetative change in central Alberta, *Canadian Journal of Earth Sciences*, Vol. 20, p. 364-376.

VERNEKAR, A. D. (1972): Long-period global variations of incoming solar radiation, *Meterological Monographs*, Vol. 12-34, p. 1-21.

WEBB, T. and BRYSON, R. A. (1972): Late- and postglacial climatic change in the northern midwest, USA: Quantitative estimates derived from fossil pollen spectra by multivariate statistical analysis, *Quaternary Research*, Vol. 2, p. 70-115.

WHITE, J. M. (1983): *Late Quaternary geochronology and paleoecology of the upper Peace River district, Canada*, Burnaby, Ph.D. thesis, 146 p.

WRIGHT, H. E. Jr. (1983): Introduction, *in Late-Quaternary Environments of the United States, Vol. 2, The Holocene*, Wright, H. E., Jr. (ed.), University of Minnesota Press, Minneapolis, p. xi-xvii.