

## Using *Picea/Pinus* Ratios from the Wilcox Pass Core, Jasper National Park, Alberta, to Investigate Holocene Timberline Fluctuations

Étude des fluctuations de la limite des arbres à l'Holocène par la mesure des taux de *Picea* et de *Pinus* présents dans une carotte prélevée à Wilcox Pass, parc national de Jasper, Alberta

Studie der Fluktuationen der Baumgrenze im Holozän unter Nutzung der *Picea/Pinus*-Anteile der Wilcox Pass-Probe, Jasper Nationalpark, Alberta

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Résumé de l'article

On a pu évaluer les différentes altitudes de la limite des arbres en comparant les taux de *Picea* et de *Pinus* présents dans la carotte, qui a été datée au radiocarbone et par tephrochronologie, avec les taux actuels enregistrés dans des échantillons de surface le long d'un tracé qui s'étend de Wilcox Pass, en végétation alpine, jusqu'à Sunwapta Pass tout près, en forêt subalpine. Les plus forts taux de pollen observés dans la carotte que dans les échantillons de surface démontrent que la limite des arbres était à une altitude supérieure entre environ 6540 et 1480 BP que maintenant, avec un minimum vers 4210 BP. Par contre, la limite des arbres était inférieure à maintenant entre environ 1480 et 540 BP, pour s'élever de nouveau après 540 BP. Ces observations concordent en grande partie avec d'autres études paléoenvironnementales effectuées dans la région. La technique ne peut toutefois s'appliquer qu'à partir du moment où le même type de végétation que celui que l'on trouve aujourd'hui s'est déjà manifesté. Pour cette raison, les taux de *Picea* et de *Pinus* enregistrés dans la carotte de Wilcox Pass avant 6540 BP environ ne peuvent être interprétés à l'aide de cette méthode.

# USING *PICEA/PINUS* RATIOS FROM THE WILCOX PASS CORE, JASPER NATIONAL PARK, ALBERTA, TO INVESTIGATE HOLOCENE TIMBERLINE FLUCTUATIONS\*

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**ABSTRACT** Holocene timberline fluctuations are investigated using *Picea/Pinus* ratios from the tephra and radiocarbon-dated Wilcox Pass Core (52°14'N, 117°13'W). Timberline elevations are calibrated by comparing *Picea/Pinus* ratios from the core with modern ratios obtained in surface samples of a transect from alpine vegetation in Wilcox Pass into subalpine forest in adjacent Sunwapta Pass. Ratios higher than present ratios from the site imply higher-than-present timberline elevation. The *Picea/Pinus* ratios imply higher-than-present timberline between ca. 6540-1480 yr BP, with a minimum about 4210 yr BP, while timberline was lower than present between ca. 1480 — 540 yr BP and increased in elevation after 540 yr BP. This record substantially agrees with other palaeoenvironmental records from the region. The main limitation on the technique is that it can only be applied since similar-to-present vegetation became established in the area. Hence, *Picea/Pinus* ratios from the Wilcox Pass core prior to ca. 6540 yr BP cannot readily be interpreted by this method.

**RÉSUMÉ** Étude des fluctuations de la limite des arbres à l'Holocène par la mesure des taux de *Picea* et de *Pinus* présents dans une carotte prélevée à Wilcox Pass, parc national de Jasper, Alberta. On a pu évaluer les différentes altitudes de la limite des arbres en comparant les taux de *Picea* et de *Pinus* présents dans la carotte, qui a été datée au radiocarbène et par tephrochronologie, avec les taux actuels enregistrés dans des échantillons de surface le long d'un tracé qui s'étend de Wilcox Pass, en végétation alpine, jusqu'à Sunwapta Pass tout près, en forêt subalpine. Les plus forts taux de pollen observés dans la carotte que dans les échantillons de surface démontrent que la limite des arbres était à une altitude supérieure entre environ 6540 et 1480 BP que maintenant, avec un minimum vers 4210 BP. Par contre, la limite des arbres était inférieure à maintenant entre environ 1480 et 540 BP, pour s'élever de nouveau après 540 BP. Ces observations concordent en grande partie avec d'autres études paléoenvironnementales effectuées dans la région. La technique ne peut toutefois s'appliquer qu'à partir du moment où le même type de végétation que celui que l'on trouve aujourd'hui s'est déjà manifesté. Pour cette raison, les taux de *Picea* et de *Pinus* enregistrés dans la carotte de Wilcox Pass avant 6540 BP environ ne peuvent être interprétés à l'aide de cette méthode.

**ZUSAMMENFASSUNG** Studie der Fluktuationen der Baumgrenze im Holozän unter Nutzung der *Picea/Pinus*-Anteile der Wilcox Pass-Probe, Jasper Nationalpark, Alberta. Die Fluktuationen der Baumgrenze im Holozän werden unter Nutzung der *Picea/Pinus*-Anteile des mittels Tephra und Radiokarbon datierten Wilcox Pass-Probe (117°13'W, 52°14'N) untersucht. Die verschiedenen Höhen der Baumgrenze wurden kalibriert, indem man *Picea/Pinus*-Anteile der Probe verglich mit gegenwärtigen Anteilen, welche aus Oberflächenproben entlang einem Längsschnitt gewonnen wurden, der von der alpinen Vegetation im Wilcox Pass bis zum subalpinen Wald im angrenzenden Sunwapta Pass reicht. Höhere Anteile als die gegenwärtigen von dieser Stelle bedeuten, daß die Baumgrenze höher war als gegenwärtig. Die *Picea/Pinus*-Anteile lassen für die Zeit zwischen etwa 6540 — 1480 Jahren v.u.Z. auf eine höhere Baumgrenze als gegenwärtig schließen mit einem Minimum vor etwa 4210 Jahren v.u.Z., als die Baumgrenze niedriger war als heute zwischen etwa 1480 — 540 Jahren v.u.Z. und dann nach 540 Jahren v.u.Z. wieder anstieg. Dieser Beleg stimmt im wesentlichen mit anderen Paläo-Umwelt-Belegen von diesem Gebiet überein. Diese Technik hat ihre Grenze darin, daß sie nur ab dem Zeitpunkt eingesetzt werden kann, wo sich in diesem Gebiet eine Vegetation durchsetzte, die der heutigen gleicht. Folglich können *Picea/Pinus*-Anteile der Wilcox Pass-Probe, die aus der Zeit von vor 6540 Jahren v.u.Z. stammen, nicht ohne weiteres mit dieser Methode interpretiert werden.

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## INTRODUCTION

This paper explores the use of pollen ratios to infer Holocene timberline fluctuations by a case study of a core from Wilcox Pass, an alpine site in Jasper National Park, Alberta (Figs. 1 and 2). The methodology of the investigation of timberline fluctuations, as discussed by MAHER (1963; 1972) and KEARNEY (1981), involves firstly calibrating the position of the present timberline with respect to the sample site by examining modern pollen ratios derived from an elevational transect (Fig. 3) and, secondly, comparing the apparent elevation of the site (based on pollen ratios from the core) to the present elevation of the site. Apparent elevation is obtained by matching the pollen ratio from the sample to the appropriate elevation from the modern pollen record (Figs. 3 and 4). Higher-than-present ratios give a lower apparent site elevation but indicate that timberline was higher than present (Fig. 4 b). Conversely, lower-than-present ratios give a higher apparent site elevation and indicate that timberline was lower than present (Fig. 4 c). Hence, *Picea/Pinus* pollen ratios from the Wilcox Pass core are compared with modern ratios from a transect from alpine areas in Wilcox Pass into subalpine fir-Engelmann spruce forest in adjacent Sunwapta Pass (Figs. 2 and 3). It is assumed that *Picea* pollen is derived mainly from

the local subalpine forest vegetation, whereas diploxylon type *Pinus* pollen, derived principally from lodgepole pine, has a more regional source. Hence, an increase in *Picea/Pinus* ratios at the alpine site implies that the subalpine forest was closer to the site, therefore that timberline elevation increased (Fig. 4). KEARNEY (1981, 1982), working in Jasper National Park, found a correlation between seedling establishment at timberline and warmer than average mean minimum summer temperatures. This suggests that higher timberlines reflect times of warmer climate (see also LaMARCHE, 1973). However, lags in vegetation response to climatic change may mean that present timberline position may not be reflecting present temperatures directly, but conditions some years previously when seedling establishment occurred. With suitable calibration, this technique might yield quantitative estimates of timberline position and possibly of temperature changes. Limitations on the technique will also be examined in this paper.

## DESCRIPTION OF THE WILCOX PASS AND SUNWAPTA PASS AREA

The Wilcox Pass and Sunwapta Pass area is situated in the Main Ranges of the Canadian Rockies, adjacent to the Athabasca Glacier, an outlet from the Columbia Icefield (Figs. 1 and 2). Bedrock is mainly Ordovician limestone and dolomite (ASPLER, 1975) which is exposed in ridges in Wilcox Pass. Although close to the Columbia Icefield, the area has not been glaciated since the early Holocene. In the middle Canadian Rockies, LUCKMAN and OSBORN (1979) found consistent evidence for only two glacial advances, the Crowfoot (Late Wisconsinan/early Holocene) and Cavell (Late Neoglacial) advances, subsequent to the Wisconsinan deglaciation. A large, tree-covered ridge adjacent to recent deposits of the Athabasca Glacier has been attributed to the Crowfoot Advance (LUCKMAN and OSBORN, 1979; Fig. 2). The oldest radiocarbon date yet obtained from Sunwapta Pass, outside the Crowfoot limit, is  $8100 \pm 100$   $^{14}\text{C}$  yr BP (GSC-2589; LUCKMAN *et al.*, 1977). Wilcox Pass, further north and at a higher elevation (Fig. 2) has been ice-free throughout the Holocene, based on a  $9600 \pm 305$   $^{14}\text{C}$  yr BP (GX-8785) radiocarbon date from the Wilcox Pass core.

The vegetation of the area was recently described as part of a biophysical inventory of Jasper and Banff National parks (HOLLAND and COEN, 1982). Basically three vegetation zones occur (Fig. 2). The valley floor of Sunwapta Pass is occupied mainly by bogs, vegetated by sedges (Cyperaceae) and mosses with shrubby vegetation, principally willows and dwarf birch (*Salix* spp. and *Betula glandulosa*) on more elevated drier sites. Subalpine forest, dominated by Engelmann spruce and subalpine fir (*Picea engelmannii* and *Abies lasiocarpa*) with an understory mainly of willows and dwarf birch, occupies the valley sides. Lodgepole pine (*Pinus contorta*), although present in the area, does not form extensive pure stands. Some whitebark pine (*Pinus albicaulis*) is also found, mainly near timberline. Above the krummholz zone, alpine vegetation occurs in Wilcox Pass, with *Salix* and *Dryas* as major components. Present timberline is found below the lip of Wilcox Pass at about 2080 m, while treeline occurs at about 2290 m.

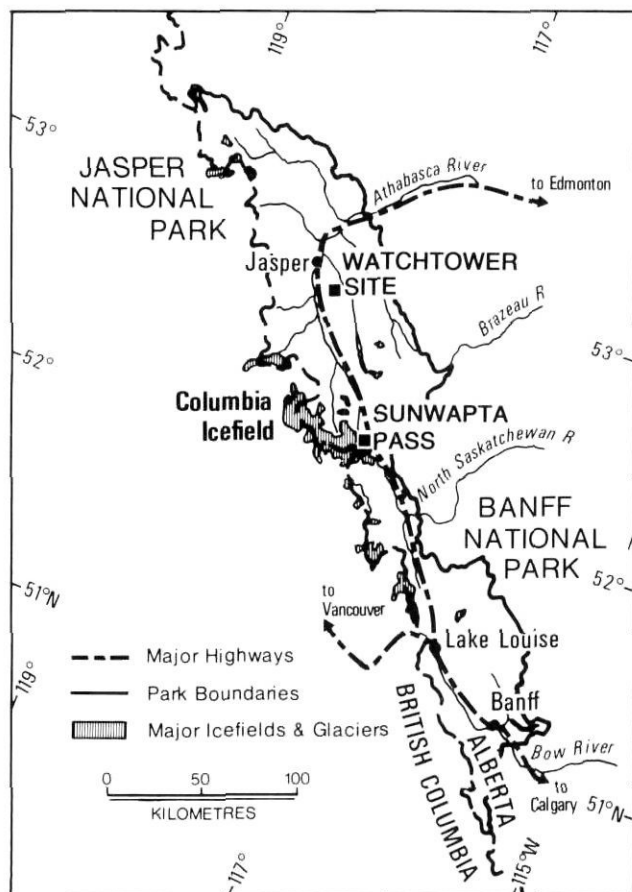


FIGURE 1. Location of the Sunwapta Pass area, Jasper National Park.

Localisation de la région de Sunwapta Pass, parc national de Jasper.

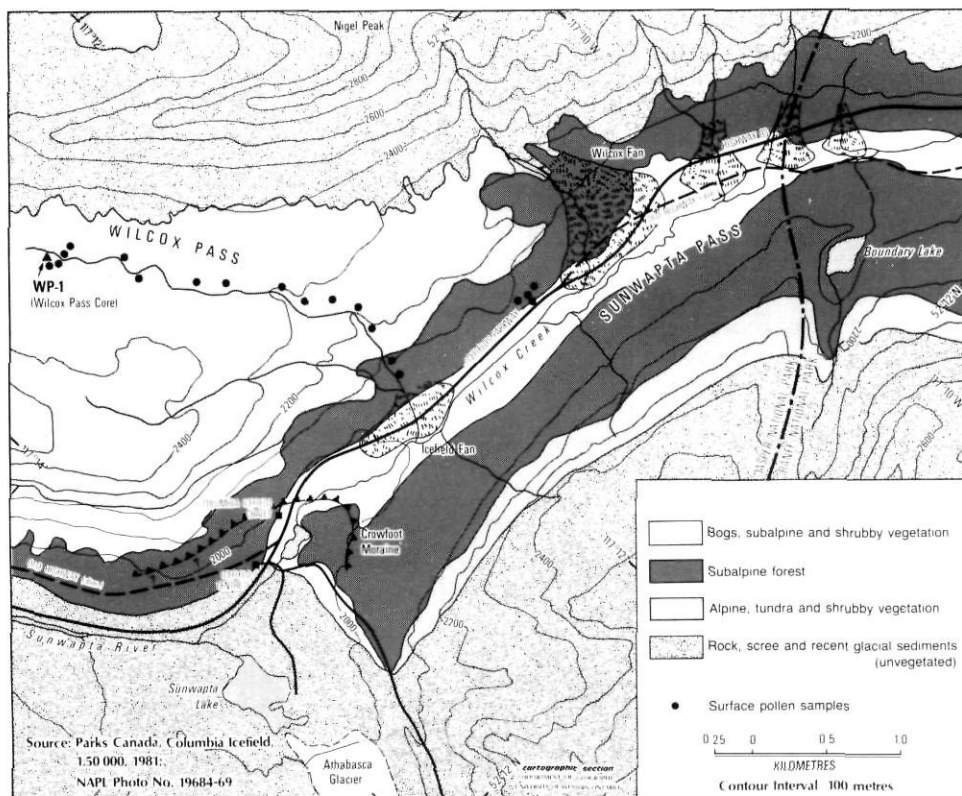


FIGURE 2. The Sunwapta Pass area showing surface pollen sampling sites, vegetation zones and the location of the Wilcox Pass core.

Carte de la région de Sunwapta Pass qui montre les sites d'échantillonnage du pollen de surface, les zones de végétation et la localisation du site de carottage de Wilcox Pass.

## METHODS

The 2.74 m Wilcox Pass core was obtained, using a modified Livingstone corer, from a shallow bedrock basin. The deposits in the lower part of the core are dominantly clastic, mainly silty, and carbonate-rich, becoming more organic towards the surface. Due to limited throughput of water and lack of significant sediment source upstream, the site has probably been unaffected by large influxes of sediment during the Holocene. The vegetation history inferred from the pollen record of the Wilcox Pass core is described in detail elsewhere (BEAUDOIN, 1984).

Dating control for the Wilcox Pass record is provided by radiocarbon dates and tephra. Two radiocarbon dates were obtained from organic material from the core:  $540 \pm 50$   $^{14}\text{C}$  yr BP (Beta-6806) at 18-22 cm depth and  $9600 \pm 305$   $^{14}\text{C}$  yr BP (GX-8785) at 192-200 cm depth. Tephra first occurs in quantity at 173-175 cm depth (Fig. 5). This tephra resembles Mazama tephra, based on electron microprobe analysis of glass-encased titanomagnetites and glass shard morphology (BEAUDOIN, 1984; BEAUDOIN and KING, 1986). The Mazama tephra in the western Cordillera is dated at 6700 yr BP (WESTGATE and GORTON, 1981). Dates for intermediate parts of the record are estimated by assuming constant sedimentation rates between the dated layers.

Present timberline position is calibrated by examining pollen ratios derived from a modern pollen transect (Figs. 2 and 3). Modern pollen spectra are obtained from moss polsters. Pollen was prepared for microscope examination using standard chemical methods (FAEGRI and IVERSEN, 1975; BATES *et al.*, 1978; BEAUDOIN, 1984), and the residues were stained with safranin and mounted in silicone oil (2000 cs viscosity). Samples were examined, using a Wild-Leitz SM-Lux microscope, at magnifications 400X and 1000X. Pollen and spores were identified using a reference collection, belonging to K. B. Cawker, and several keys, including KAPP (1969), McANDREWS *et al.* (1973), and BASSETT *et al.* (1978). Pollen sums usually exceed 300 grains.

Pine pollen was identified as haploxylon or diploxylon type where possible; types distinguished by the presence/absence of distal verrucae (TING, 1966) were assigned to subgenera (BAKER, 1976). It is assumed that both types degrade equally and that the proportions found in the identified count may be applied to the pine count as a whole. When calculating *Picea/Pinus* ratios, the *Pinus* values are "corrected" for the amount of haploxylon type pine pollen, so that the ratios reflect only the amount of diploxylon type pine pollen.

## CALIBRATION OF THE PRESENT TIMBERLINE

Examination of *Abies/Pinus*, (*Abies* + *Picea*)/*Pinus* and *Picea/Pinus* ratios, derived from 71 surface samples from throughout the Wilcox Pass and Sunwapta Pass area, showed that *Picea/Pinus* ratios are most sensitive to change in vegetation type (BEAUDOIN, 1984). *Picea/Pinus* ratios are generally  $> 0.8$  in the subalpine forest and  $< 0.8$  on the subalpine bogs in Sunwapta Pass or in alpine areas in Wilcox Pass. Samples in the krummholz zone, between treeline and timberline, have lower ratios which more closely resemble the ratios from more open areas above treeline than those from

the subalpine forest. The *Picea/Pinus* ratios, therefore, display a recognisable relationship with vegetation types and may be used to infer elevation above the present timberline. When the *Picea/Pinus* ratios from the Wilcox Pass transect are plotted against elevation (Fig. 3) a clear trend is seen, although with some variability; the cluster of points at 2350 m reflects the crest of the Pass while the few points on this transect between ca. 2250 and 2100 m reflect the steep rocky slopes at the lip of Wilcox Pass.

Several assumptions are inherent in this method. It is assumed that the *Picea* pollen is derived locally from the subalpine forest whereas the *Pinus* pollen is derived mainly from regional sources and is acting as an almost constant background input. This assumption seems reasonable given the well-known tendency for pine pollen to be over-represented in pollen spectra and to be found at great distances from its source (FAEGRI and IVERSEN, 1975), and the extensive areas of lodgepole pine-dominated forest found at lower elevations (see HOLLAND and COEN, 1982). However, the wind pattern in mountains is highly variable (JANZ and STORR, 1977) and could influence, for example, the distance that the rapidly-settling *Picea* pollen is carried upslope. For instance, in a study of pollen dispersal in the Swiss Alps, MARKGRAF (1980) found that pollen from low elevations showed a relative increase at high elevations due to the low pollen productivity at high elevations and the upslope wind direction.

Another fundamental assumption is that the relationship between slope and elevation is relatively constant and therefore that elevation can be used as a surrogate measure of distance from timberline. In Wilcox Pass, slope is not constant (Fig. 2) and hence in this case elevation is not a simple surrogate measure for distance from the timberline. The forest generally inhabits the steeper valley side slopes whereas the floors of both Wilcox Pass and Sunwapta Pass have relatively gentle slopes (Fig. 2). Also, the configuration of the slope is likely to affect wind patterns and microclimate, which thereby would influence tree distribution. Thus, where topographic discontinuities are involved, these may interact with local environmental factors to influence vegetation distribution, independent of elevation relationships. This analysis is therefore site-specific; using *Picea/Pinus* ratios from one area to interpret records from a different area would be unwise.

Increased *Pinus* relative to *Picea* pollen may be related to fire. Fire incidence may be related to climate but at one remove further than direct climatic influence on the vegetation. Moreover, in this relatively marginal area, forest may take a long time to re-establish after a fire (HABEK and MUTCH, 1973), and thus timberline may be lower for some considerable time. Fire incidence in the settled areas, for example, around Jasper townsite, is likely to have been much greater in the early years of settlement in the last century and would also have been increased by the construction of the railway (NELSON and BYRNE, 1969). Therefore lodgepole pine is likely to be more dominant in the regional vegetation in some areas now than in the past. For instance, KEARNEY (1981) did not use the modern pollen data from the Signal Mountain transect, near Jasper townsite, because of the recent fire history of that area. Thus if lodgepole pine is more prevalent in the

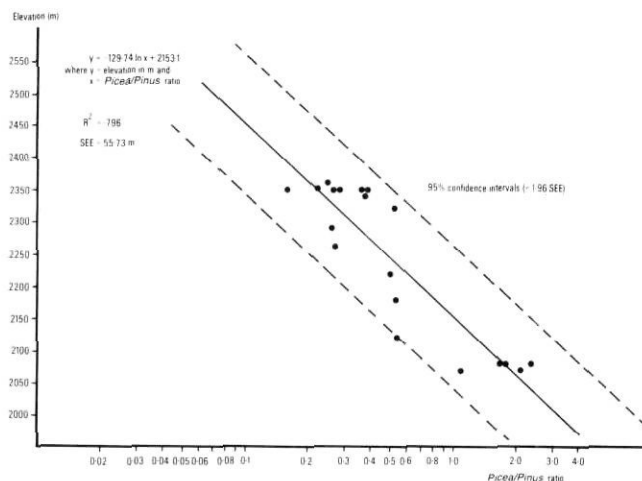


FIGURE 3. Variations in the *Picea/Pinus* ratios with elevation for the surface pollen transect from Wilcox Pass.

Variations des taux de *Picea* et de *Pinus* selon l'altitude le long du tracé de Wilcox Pass.

regional vegetation now than in the past, the past *Picea/Pinus* ratios would be higher than present ratios, leading to false implications of higher timberline and therefore warmer conditions in the past as compared to the present. However, in the Sunwapta Pass area there is no evidence for recent major fires leading to increased extent of lodgepole pine and therefore the present ratios are probably not unduly influenced by this factor.

### HOLOCENE TIMBERLINE FLUCTUATIONS INFERRED FROM THE WILCOX PASS CORE

The ratio/elevation diagram for the present *Picea/Pinus* ratios (Fig. 4) is used to plot the apparent elevation for the *Picea/Pinus* ratios from the Wilcox Pass core (Fig. 5). Using the equation developed from the modern samples, the upper sample from the core predicts the present apparent elevation of the site quite well, giving an estimate only 20 m higher than the actual elevation.

Four main phases of *Picea/Pinus* ratio fluctuations can be identified from this data. Low *Picea/Pinus* ratios (<.15) occur from the base of the record to about 195 cm depth, including pollen zones WP1, WP2, and the lower part of Zone WP3. This phase occurs below the  $9600 \pm 305$  yr BP (GX-8785) radiocarbon date. Generally high ratios (>.2) occur from 195-43 cm depth. Throughout this phase, a general trend can be seen from very high ratios (>.25) between 195-170 cm depth, with a gradual decline to .21 ratio at 111.5 cm depth, followed by an increase to .29-.34 ratios between 75-43 cm depth. This general trend is interrupted by a ratio of .94 at 175.5 cm depth, which reflects the high amount of haploxylon type pine pollen in this sample. The inferred dates for this phase are 9600-1480 yr BP and it includes most of Zones WP3, WP4, and the lower part of Zone WP5. This is followed by a short phase, between 43-20 cm depth, during which the ratios fell to a low of .08. This phase has an estimated age of 1480-540 yr BP. Finally, from 20 cm to the surface, from 540 yr BP

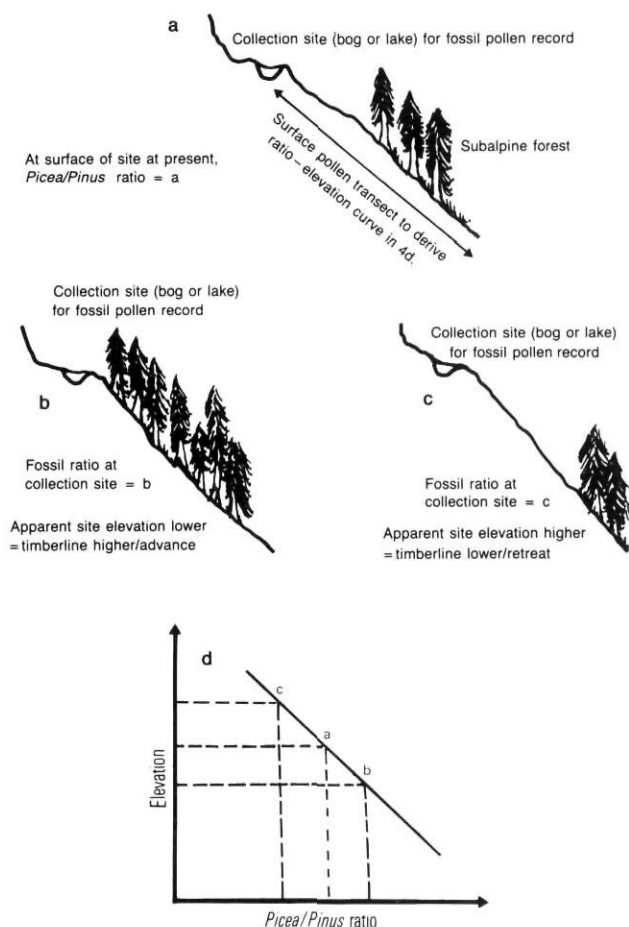


FIGURE 4. Schematic diagram showing relationships between elevation and ratios with timberline fluctuations.

Diagramme schématisé montrant les relations qu'entretiennent l'altitude et les taux de pollen avec les fluctuations de la limite des arbres.

to the present, *Picea/Pinus* ratios are relatively high. This phase includes the upper part of Zone WP5.

Not all these phases should be interpreted as reflecting climatically-induced timberline fluctuations. The calibration curve derived from present vegetation can only be used to interpret the past record since similar vegetation to present became established in the area. For instance, the complete pollen record from the Wilcox Pass core (BEAUDOIN, 1984) indicates that the vegetation of the early zones (WP1, WP2 and WP3) was different to present vegetation. In Zone WP1, for example, a pollen assemblage dominated by *Artemisia* implies that the landscape was probably almost treeless. In Zones WP1 and WP2, *Picea/Pinus* ratios imply a higher apparent site elevation and therefore cooler conditions. But the lack of *Picea* is probably related to site instability, lack of available suitable soils and sites, and slower migration of spruce into the area. However, large amounts (ca. 85 %) of *Pinus* (mainly diploxylon type) pollen in Zone WP2 are associated with small amounts (ca. 1 %) of *Arceuthobium* pollen. Because *Arceuthobium* is a parasite on pine and its pollen is not usually far dispersed from the parent plant (GREGOR

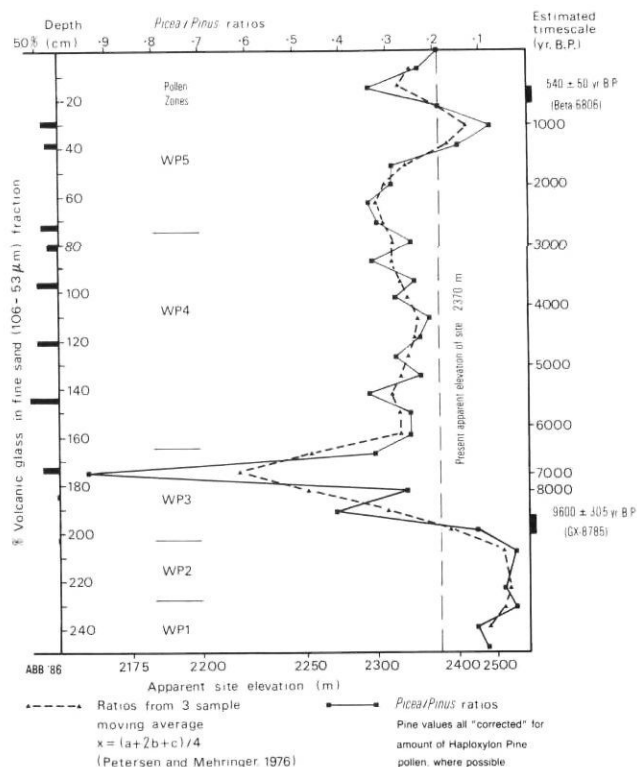


FIGURE 5. Apparent site elevations based on *Picea/Pinus* ratios from the Wilcox Pass core.

Altitudes probables des sites fondées sur les taux de *Picea* et de *Pinus* enregistrés dans la carotte de Wilcox Pass.

*et al.*, 1974), this implies that trees must have been closer to the site than present. The overall view thus implies a higher-than-present timberline and possibly warmer than present conditions during Zone WP2; a contrasting conclusion to that obtained by examining the *Picea/Pinus* ratios alone. Therefore, palaeoclimatic inferences solely from the ratios are misleading as climate is probably not the main limiting factor controlling the relative amounts of *Pinus* and *Picea* in Zones WP1 and WP2. Similarly, in Zone WP3, the *Picea/Pinus* ratios imply higher timberline, but, from the pollen record, haploxylon pine was a major component of the vegetation at this time (BEAUDOIN, 1984). Hence, the forest composition was not the same as at present and the ratios alter because the *Pinus* values are "corrected" for the amount of haploxylon pine. However, from the later part of Zone WP3, from ca. 170 cm depth, and during Zones WP4 and WP5, vegetation similar to present vegetation occurred in the area, and therefore fluctuations in the *Picea/Pinus* ratios may have interpretative significance in terms of timberline fluctuations and possibly climate.

The generally higher-than-present ratios from 170-43 cm depth imply a prolonged period of middle Holocene higher-than-present timberline. A sustained period of middle Holocene higher-than-present timberline has been reported from other areas, for example, by LaMARCHE (1973) from the White Mountain area of California. If upper timberline position is related to summer temperatures, this implies that, for much of the Holocene (at least from ca. 6540-1480 yr BP), summer

temperatures in the Wilcox Pass and Sunwapta Pass area have generally been warmer than present.

However, within this phase, conditions did not remain uniform. The general decline in ratios between 170 ca. 111.5 cm depth, with an estimated age of 6540-4210 yr BP, imply a gradually falling timberline with deteriorating conditions and possibly cooler temperatures. Other environmental records from the Canadian Rockies show a change from an early Holocene phase of maximum warmth to colder and wetter conditions, after the Mazama ash fall, around 6000 yr BP (see OSBORN, 1982; KEARNEY, 1981). Moreover, recent radiocarbon dates from the Boundary Glacier, an outlet from the Columbia Icefield about 5 km southeast of Wilcox Pass, suggest that a Neoglacial ice advance occurred ca. 4000 yr BP (GARDNER and JONES, 1985). The lower ratios ca. 4000-4500 yr BP in this record correlate well with these observations.

From the low ratio at 111.5 cm depth, ratios gradually increase to a maximum of .34 at 63.5 cm depth, with an estimated age of 2290 yr BP. This implies a gradual rise in timberline elevation, possibly related to a warming trend. OSBORN (1982) cites evidence which suggests a higher-than-present timberline at Peyto Glacier just prior to  $2880 \pm 170$   $^{14}\text{C}$  yr BP (GSC-1155). KEARNEY (1981) also suggests warmer than present temperatures ca. 3330 yr BP followed by a transition to cooler and wetter conditions after ca. 1700 yr BP from analysis of the Maligne Lake core.

*Picea/Pinus* ratios have been more variable during Zone WP5, implying that timberline elevations have been more variable in the last two millennia. This correlates with other records, e.g. KEARNEY (1981), which suggest that the late Holocene has become colder and/or wetter. The low ratio at 31.5 cm depth, with an estimated age of 1020 yr BP implies a low timberline phase. This is inconsistent with the occurrence of snags on the slope behind the Icefield Chalet (LUCKMAN, 1982; Fig. 2) which suggests higher-than-present timberline at this time. A similar discrepancy between pollen and macrofossil evidence was noted by ANDREWS *et al.* (1975) in the San Juan Mountains. The apparent discrepancy may be due to different dating control for the two sets of evidence. Alternatively, the apparent timberline retreat may be a response to some factor other than climate. However, some climatic fluctuations appear to occur quite rapidly, for example, studying tree-limit fluctuations in Scandinavia, KARLEN (1983) found evidence of glacier advances ca. 1200-1000 yr BP while wide tree rings suggested that the climate was warmer until 1250 yr BP and between 1000-900 yr BP. With substantial changes on the scale of only a few hundred years, discrepancies between different environmental indicators, which have different response times, might be expected.

Timberline fluctuations may be related to climatic change and, specifically, temperature fluctuations, although other climatic components and environmental factors cannot be ruled out. For example, higher summer temperatures, possibly with a decrease in precipitation, might lead to moisture deficiency for trees growing on the shallow and freely-draining soils near the upper timberline in Sunwapta Pass. This might result in

a lowering of timberline at times of higher temperatures. However, KEARNEY (1981, 1982) found that seedling establishment in Sunwapta Pass was positively correlated with recent warmer mean minimum summer temperatures.

## COMPARISON OF THE WILCOX PASS AND WATCHTOWER BASIN RECORDS

Another timberline fluctuation record from Jasper National Park is available from Watchtower Basin (Fig. 1; KEARNEY, 1981; KEARNEY and LUCKMAN, 1983). The Wilcox and Watchtower records show several similarities. The early part of the Wilcox Pass record predates the Watchtower record. The base of the Watchtower record is estimated at ca. 8100-8500 yr BP (KEARNEY and LUCKMAN, 1983). Both records show an early Holocene phase of higher-than-present ratios. In the Watchtower record this phase lasted from about 8500 to 5900 yr BP but was interrupted by timberline retreat (= lower ratios) at about 6900 yr BP (KEARNEY and LUCKMAN, 1983). The second phase of higher-than-present timberline, between ca. 6700-5900 yr BP, appeared at least as warm as the earlier phase, judging by the apparent elevation data (KEARNEY and LUCKMAN, 1983). In the Wilcox Pass record, the early high ratios cannot be interpreted in terms of timberline elevations. However, the Wilcox Pass record does indicate that timberline was higher-than-present when subalpine forest became established in the area towards the close of Zone WP3, ca. 6540 yr BP (Fig. 5).

The Wilcox Pass record shows decreasing timberline elevations between 6540-4210 yr BP, followed by increasing timberline elevations to 1480 yr BP, culminating at about 2300 yr BP. Timberline fell quite sharply after 1480 yr BP. This middle Holocene record appears somewhat different from that recorded by the Watchtower Basin. However, the period from 5900-ca. 1600 yr BP is a fairly short segment of the Watchtower record, about 10 cm of sediment, reflecting decreased sedimentation rates (KEARNEY and LUCKMAN, 1983). Even in this compressed record, timberline was apparently higher at the close of this interval (KEARNEY and LUCKMAN, 1983), which matches the Wilcox Pass record at this time.

Both records show substantial timberline retreat after ca. 1600 yr BP. In the Watchtower Basin, two brief reversals of this trend occurred at ca. 1000 and 500 yr BP, while timberlines reached their lowest recorded elevation sometime after 500 yr BP (KEARNEY and LUCKMAN, 1983). In the Wilcox Pass record only one reversal is seen, at about 430 yr BP when timberlines were apparently at least as high as during the middle Holocene. Timberlines reached their lowest elevation since the initial part of the record at ca. 1020 yr BP.

It is difficult to assess the impact of local conditions and site differences on the timberline fluctuation records. Site-specific factors may account for the differences in the records in the middle Holocene. For instance, evidence of past higher timberline in the Watchtower Basin and Maligne Pass was supported by logs recovered from the sites (KEARNEY and LUCKMAN, 1983). No such evidence has been found in Wilcox Pass. Wilcox Pass contains shallow soils and bedrock outcrops.

Thus higher timberlines may have been controlled not only by temperature limitations but also by edaphic factors and site availability. The Wilcox Pass core was interpreted using *Picea/Pinus* ratios, whereas KEARNEY and LUCKMAN (1983) used *Abies/Pinus* ratios to interpret the Watchtower Basin record. The response of *Picea* and *Abies* to climatic changes may differ. This might explain some variation between the records.

Overall, however, the timberline fluctuation records from Wilcox Pass and Watchtower Basin match quite well. This suggests that generally the timberline fluctuations are reflecting regional climatic trends.

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