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Pollen evidence of Late Holocene treeline fluctuation from the southern Coast Mountains, British Columbia

Les fluctuations de la limite des arbres à l'Holocène supérieur dans le sud des montagnes Côtières (Colombie-Britannique) signalées par les données polliniques

Palynologische Belege über Spätholozäne Baumgrenze Verschiebungen in den südlichen Coast Mountains von British Columbia

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Résumé de l'article

Le relevé pollinique des changements climatiques de l'Holocène dans le sud des montagnes Côtières a permis d'identifier une période néoglaciaire après 6 600 BP, plus froide et humide que l'Hipsithermal qui la précédait. Les indices géomorphologiques semblent pourtant indiquer trois périodes distinctes de climat plus froid et humide au cours du Néoglaciaire. Grâce au choix minutieux d'un site alpin sensible aux variations, on a pu identifier deux de ces périodes à partir du relevé palynologique. On a évalué les spectres polliniques, les macrofossiles d'aiguilles de pin, la teneur en matière organique et la sensibilité magnétique d'une séquence de sédiments en provenance du Blowdown Lake, dont la date basalep est inférieure à 4 000 ans. La comparaison des taux de *Picea-Pinus* dans la carotte et dans les échantillons de surface montre que la limite des arbres était au moins à 100 au-dessus de la limite actuelle jusqu'à 3 400 BP, avec des températures estivales d'au moins 0,7 °C de plus que maintenant. La limite des arbres a reculé près de sa position actuelle vers 2 400 BP. Deux autres périodes froides subséquentes ont été identifiées ; elles semblent coïncider avec les périodes d'avancée glaciaire du Tiedemann et du Néoglaciaire supérieur dans le sud de la Colombie-Britannique. Les différences entre les taux de *Picea-Pinus* et d'*Abies-Pinus* dans la carotte concordent avec l'autoécologie de ces espèces. Ces résultats montrent que le succès de l'approche des taux polliniques pour la reconstitution des limites des arbres dépend des taux choisis.

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POLLEN EVIDENCE OF LATE HOLOCENE TREELINE FLUCTUATION FROM THE SOUTHERN COAST MOUNTAINS, BRITISH COLUMBIA

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ABSTRACT Palynological records of Holocene climate change in the southern Coast Mountains identify the Neoglacial period, subsequent to 6600 BP, as cooler and wetter than the preceding Hypsithermal. However, geomorphic evidence of alpine glacier advance suggests that there were three distinct cooler/wetter periods during the Neoglacial. By careful selection of a sensitive alpine site this study has enabled the recognition of two of these stages in a palynological record of Neoglacial climate. Pollen spectra, conifer needle macrofossils, organic matter content, and magnetic susceptibility were assessed for a continuous sequence of sediment from Blowdown Lake, which has a basal date older than 4000 BP. Comparison of the *Picea/Pinus* pollen ratios from the core with modern surface samples suggests that treeline was at least 100 m above its present elevation until 3400 BP, indicating that summer temperatures were at least 0.7°C above the present. Treeline declined to near present levels by around 2400 BP. Two subsequent periods of lower treeline were identified which appear to correlate approximately with the Tiedemann and Late Neoglacial periods of glacier advance in southwestern British Columbia. Differences between *Picea/Pinus* and *Abies/Pinus* ratios from the core are consistent with the autecology of the species. This suggests that the sensitivity of the pollen ratio approach to reconstructing treeline is dependent on the ratios selected.

RÉSUMÉ *Les fluctuations de la limite des arbres à l'Holocène supérieur dans le sud des montagnes Côtières (Colombie-Britannique) signalées par les données polliniques.* Le relevé pollinique des changements climatiques de l'Holocène dans le sud des montagnes Côtières a permis d'identifier une période néoglaciaire après 6600 BP, plus froide et humide que l'Hipsithermal qui la précédait. Les indices géomorphologiques semblent pourtant indiquer trois périodes distinctes de climat plus froid et humide au cours du Néoglaciaire. Grâce au choix minutieux d'un site alpin sensible aux variations, on a pu identifier deux de ces périodes à partir du relevé palynologique. On a évalué les spectres polliniques, les macrofossiles d'aiguilles de pin, la teneur en matière organique et la sensibilité magnétique d'une séquence de sédiments en provenance du Blowdown Lake, dont la date basalep est inférieure à 4000 ans. La comparaison des taux de *Picea-Pinus* dans la carotte et dans les échantillons de surface montre que la limite des arbres était au moins à 100 au-dessus de la limite actuelle jusqu'à 3400 BP, avec des températures estivales d'au moins 0,7 °C de plus que maintenant. La limite des arbres a reculé près de sa position actuelle vers 2400 BP. Deux autres périodes froides subséquentes ont été identifiées ; elles semblent coïncider avec les périodes d'avancée glaciaire du Tiedemann et du Néoglaciaire supérieur dans le sud de la Colombie-Britannique. Les différences entre les taux de *Picea-Pinus* et d'*Abies-Pinus* dans la carotte concordent avec l'autoécologie de ces espèces. Ces résultats montrent que le succès de l'approche des taux polliniques pour la reconstitution des limites des arbres dépend des taux choisis.

ZUSAMMENFASSUNG *Palynologische Belege über Spätholozäne Baumgrenze Verschiebungen in den südlichen Coast Mountains von British Columbia.* Palynologische Belege zur Untersuchung von klimatische Änderungen des Holozäns in den südlichen Küstengebirgen von British Columbia deuten auf eine kältere und feuchtere Periode anschließend and das Neoglazial vor 6600 Jahren hin. Geomophologische Befunde von den Vorstössen alpiner Gletscher dagegen, lassen auf drei kältere and feuchtere Perioden während des Neoglazials schließen. Die vorsichtige Wahl eines vegetationssensiblen alpinem Gebietes ermöglichte es diese Perioden durch palynologische Studien zu erfassen. Pollenspektren, Makrofossilien von Koniferennadeln, Paleomagnetismus, sowie der Anteil an organischem Material wurden für eine zusammenhängende Sedimentsequenz von ungefähr 4000 Jahren am Blowdown See betrachtet. Ein Vergleich des Pollenverhältnisses *Picea* und *Pinus* deutet darauf hin, daß die Baumgrenze bis kurz vor 3400 Jahren wenigstens 100 m über der heutigen lag. Dieser Umstand kann mit mindestens 0.7°C höheren Sommertemperaturen im Vergleich zu den heutigen erklärt werden. Bis vor 2400 Jahren sank die Baumgrenze in Höhenlagen nahe der heutigen. Im Anschluß an diese Zeit wurden zwei Perioden mit niedrigeren Baumgrenzen ausgegrentzt, die ungefähr zeitgleich mit den Tiedemann und spätneoglazialen Gletscherwachstumsperioden stattfanden. Unterschiede in den Pollenverhältnissen zwischen *Picea/Pinus* und *Abies/Pinus* sind mit den ökologischen Characteristika der Spezien vereinbar und weisen darauf hin, daß die Empfindlichkeit dieses pollenanalytischen Ansatzes von den gewählten Pollenverhältnissen abhängig ist.

INTRODUCTION

The broad outline of Holocene palaeoclimate in southern British Columbia has been described by a series of palaeobotanical studies (Hansen, 1955; Heusser, 1960; Mathewes and Rouse, 1975; Mathewes, 1973; Mathewes and King, 1989; Alley, 1976; Hebda, 1982, 1995). These investigations identified patterns of regional vegetational change, which have been interpreted as being largely climatically forced. The pattern which has emerged is of an early Holocene Hypsithermal period which was warmer and drier than the present. Subsequently, between 6600 and 4000 BP, there is a poorly defined transition to cooler wetter Neoglacial conditions which persist to the present day (Mathewes, 1985). Geomorphological evidence suggests that this may be an incomplete picture of Holocene, and particularly Neoglacial climate fluctuations. Ryder and Thomson (1986) identified three distinct periods of glacier advance in the southern Coast Mountains during the Neoglacial. On the basis of ^{14}C dates and moraine stratigraphy, they identify periods of advance of alpine glaciers at 6000-5000 BP; 3300-1900 BP and 900-100 BP. These, presumably climatically driven, advances suggest that the Neoglacial climate record of the region is more complex than the available palynological data suggest. Souch (1990) regards the disparity between the two lines of evidence as an artefact of the differing sensitivity of the techniques of reconstruction, and the contingent location of the sites of investigation. This refers to the fact that the pollen record in the region is largely based on records from lowland areas where the vegetation is well within its climatic tolerances and is therefore relatively insensitive to climatic change. Alternatively it is possible that the glacial and pollen evidence record different climate information. For example, periods with increased winter precipitation may cause glacial advances which are not identifiable in a pollen record where the signal is largely summer temperature driven.

This study aims to distinguish between these two possible causes of the disparity by examining a "sensitive" Neoglacial pollen record from a site located at a climatically determined ecotone. Such a record would also:

1) provide some evidence of the nature of climate changes driving Neoglacial ice advances;

2) provide a continuous record of Neoglacial change in contrast to the discontinuous nature of the geomorphological record;

3) provide insight into the sensitivity and representativeness of the regional pollen record.

SITE SELECTION

In order to investigate these ideas a sensitive pollen site was sought in the southern Coast Mountains of B.C. The steepest climatic gradients in the region are typically associated with elevational change. The most clearly defined elevational ecotone is treeline. Treeline here is used to refer to the transition from erect growth forms to stunted krummholz forms.

The treeline ecotone has been widely studied (e.g. Arno and Hammerly, 1984). In particular, Tranquilini (1979) clearly outlined the effects of severe alpine climate on tree physiology, suggesting treeline is controlled by a requirement for adequate summer warmth which correlates with an annual mean temperature of 10°C. Although temperature sets a theoretical maximum treeline altitude, the actual altitude may be lower due to other environmental constraints. In an attempt to avoid non-climatic and indirect climatic influences on treeline altitude (e.g. large snowpack, avalanche activity, insect infestation, edaphic constraints, biological controls) the following site selection criteria were adopted. Site selection was confined to areas without excessive winter snowpack, where treeline occurred at constant elevation, and was not unusually low in the regional context, and finally, where there were no apparent edaphic limitations to treeline expansion

SITE

Blowdown Lake fulfilled the site selection criteria. It is a small (200 m diameter), oligotrophic lake at treeline (2025 m), in the southern Coast Mountains of B.C. (Figs. 1 and 2). The lake is in a large westerly facing cirque, and has two inflows, one a steep rocky channel from the east and the other a smaller stream from the base of avalanche slopes to the north.

No instrumental climate record is available for the site. In 1992, the site was clear of snow by June 1, and in 1993, before June 25th. To the north of the lake, behind a ridge with northerly aspect, is a series of creeping talus slopes and small rock glaciers. At least one appears to be active suggesting a mean annual ground temperature close to, or below 0°C. Table I .presents the closest comparable climate

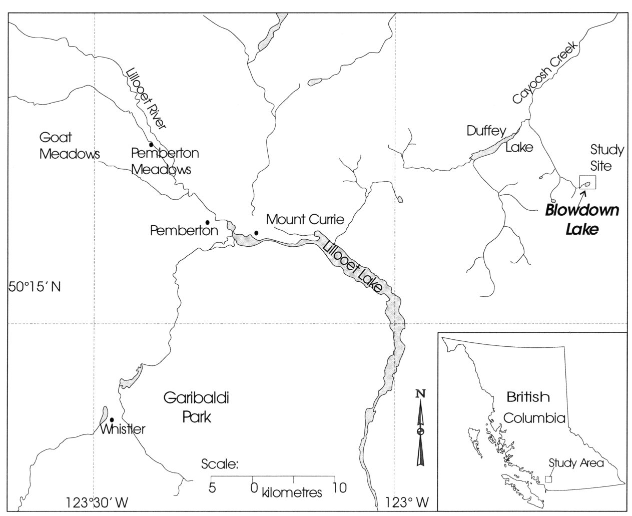

FIGURE 1. Sketch map of the location of Blowdown Lake.

Carte de localisation du Blowdown Lake.

data from Goat Meadows (Gallie, 1983; Gallie and Slaymaker, 1984, 1985; Owens, 1990) This site lies at 1700 m, 50 km west and 20 km north of Blowdown Lake in the Coast Mountains, west of the town of Pemberton. The range of temperature at Goat Meadows is likely to be similar to the Blowdown area. However, the precipitation is probably somewhat higher because the Goat Meadows site is further west, and more subject to oceanic influence.

FIGURE 2. Photograph of Blowdown Lake.

Photographie du Blowdown Lake.

TABLE I

Climate data from the Goat Meadows Watershed

Annual precipitation	>1800 mm
	70 - 80% as snow
Mean annual air temperature	0 -1°C (1979)
May 1 Snowpack	1500 mm water equivalent

Data taken from Owens, 1990; Gallie, 1983. Data are estimates based on comparison of 1979-1980 data with longer records from nearby snow courses and weather stations.

Blowdown Lake lies on a lithological boundary between quartz diorite and granodiorite. The bedrock is partially covered by sandy Coast Mountain till and soil development is minimal except in the wet meadows where a humic gleysol has developed. In the wettest areas, thick organic soils have developed. The site lies on the transition between the Coastal Mountain Hemlock biogeoclimatic zone and the interior Engelmann Spruce-Subalpine Fir zone (Meidinger and Pojar, 1991). Observations of the vegetation at the site identify a transition from subalpine forest below the lake to scattered tree islands around it. This forest is dominated by *Abies lasiocarpa* and *Picea engelmannii* with occasional *Pinus monticola*. The tree islands are dominated by *Abies lasiocarpa*. The parkland understory is highly differentiated, the principal control being moisture variability due to microtopography. Dry sites are dominated by *Cassiope mertensiana* and *Phyllodoce empetriformis.* In wetter areas, *Alnus sinuata* and two species of *Salix* are found. Immediately downslope of Blowdown Lake is a wet sedge meadow supporting various Cyperaceae, Gramineae, *Salix* spp, *Menziesia ferruginea* and abundant alpine herbs. Above the lake, krummholz forms of *Abies* are found along with Gramineae and occasional *Juniperus communis.*

METHODS

The lake was cored with a modified Livingstone corer from a specially constructed portable raft. Cores were extruded on the raft and wrapped in plastic. In addition surface sediments were collected to provide a record of modern pollen deposition around the lake. Samples of wet humus were taken along an altitudinal transect, from peaty seeps alongside a network of small streams below the lake, and from peaty seeps and small ponds (1-2 m diameter) above the lake.

On return to the lab the cores were x-rayed using chest film and Phototimer settings at UBC Hospital radiology department. The whole cores were scanned to measure magnetic susceptibility at the Pacific Geoscience Centre of the Geological Survey of Canada using a Sapphire Instruments SI-2 metre. They were then split to describe the visible stratigraphy. In total eight cores were recovered, the longest core (110 cm) from the centre of the lake (water depth 7 m) was selected for intensive study.

Samples were taken every 2 cm and ignited at 550°C for an hour to establish organic content (55 samples) (Belcher and Ingram, 1950). Five centimetres sections of half core (22 samples dry volume each approx 20 cm^3) were soaked in 3% KOH and washed through a 500 µm sieve. Needle fragments were identified and counted under the binocular microscope. Identification was by reference to Dunwiddie (1985) and the reference collection of Dr. Rolf Mathewes at Simon Fraser University. Following Wainman and Mathewes (1990), needle fragments were classified as tips, bases or mid-sections. The number of needles in the sample was calculated as (tips + bases)/2.

Samples of 2 cm^3 were removed from the cores at 5 cm intervals (a total of 25 samples) and prepared for pollen analysis using standard techniques (Faegri and Iversen, 1989). Commercial lycopodium tablets (3 @ 11300±400 spores) were added to each sample to allow absolute pollen counting.

The pollen slides were counted on a Zeiss light microscope at 400x magnification with critical identifications being made under oil immersion at 1000x. Total pollen sums were between 300 and 350 grains. Pollen identification was by reference to an unpublished dichotomous key provided by Dr. Glenn Rouse (UBC Department of Botany), atlases, primarily Moore and Webb (1978), and to the type collection belonging to Dr. Rouse. Diploxylon and haploxylon Pine were distinguished on the basis of the absence or presence of verrucae on the leptoma.

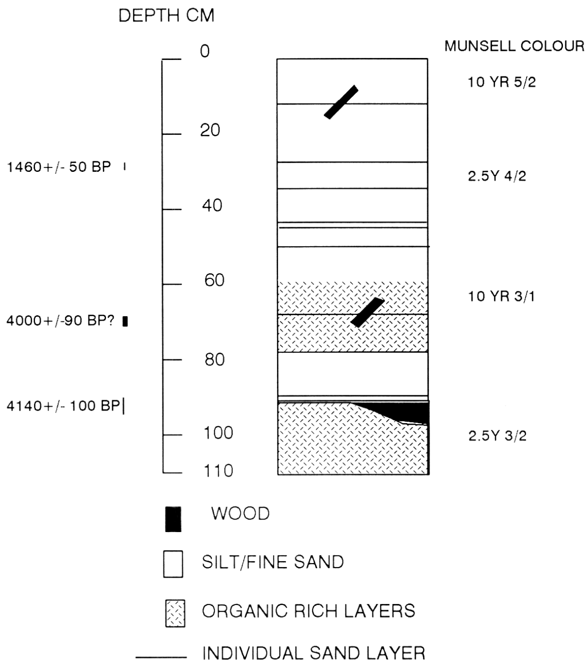

FIGURE 3. Stratigraphy of Core BD4A.

Stratigraphie de la carotte BD4A.

STRATIGRAPHY

The stratigraphy and sedimentology of the longest Blowdown Lake core (BD4A) are presented in Figure 3. The bulk of the core is composed of fine sands and silts and organics. Discrete sand layers occur throughout the core. Beneath 50 cm depth the layers are thin (1-2 mm), and of fine to medium sand, above 50 cm the sands are thicker, (up to 3 cm) and fine upwards. The thickest layers grade from fine gravel to medium sands. These upper sand layers also contain some larger clasts (up to 40 mm) and some slightly disturbed stratigraphy (apparent from the x-radiographs). These were interpreted as avalanche dropstone deposits (Luckman, 1975).

Figure 4A presents the results of loss on ignition measurements on core BD4A which identify downcore changes in organic content. The values are 12-14% LOI in the lower half of the core and then decrease gradually to lower values around 6% in the upper half of the core. The minerogenic layers discussed above are marked by minima in the LOI curve below these average values. The magnetic susceptibility curve (Fig. 4B) exhibits an inverse pattern with low susceptibility in the lower core and a marked increase above 50 cm. These patterns are interpreted as representative of higher allochthonous organic inputs to the lake (due to higher catchment productivity) in the period represented by the lower half of the core. Above 50 cm the pattern suggests decreased organic inputs along with higher rates of erosion of mineral soil.

CHRONOLOGY

Three radiocarbon dates were obtained on material from core BD4A. The core includes a large section of wood at 90-96 cm depth where the corer penetrated cleanly through a submerged log. A conventional ^{14}C date on this material yielded a date of 4140±100 BP (Beta 57762). Needles from 67 cm depth provided an AMS date of 4000±90 BP (TO 3877) and a twig from 28 cm was dated to 1460±50 BP (TO 3876). The dates from 67 and 90 cm depth are not significantly different. However, silt laminae and sand layers between the samples appear to represent several small depositional events. Therefore the two dated samples were not deposited in a single large event. These laminae also preclude the possibility that the stratigraphic separation of the samples is due to the log settling. The dated material from the 67 - 68 cm level was five conifer needles found in a sand layer that contained considerable organic matter and charcoal. Some of the material was dark and matted, suggestive of inwashed soil materials. It is suggested that the needles dated were preserved in the humic layer of a forest soil and washed into the lake at a later period during a major erosional event.

The chronology of the core is therefore assumed to be represented by dates of 1460 BP at 28 cm depth, and 4140 BP at 90 - 96 cm depth. The relatively late basal date from the lake is probably due to the rocky nature of the lake floor. The adjacent cliff is a major source of rockfall input to the lake, and boulders in the lake sediment prevented the recovery of long cores.

CONIFER NEEDLE MACROFOSSILS

Figure 4C shows the downcore variability in the occurrence of conifer needle macrofossils in core BD4A. The major feature of this plot is the shift from higher concentrations of needles below 60 cm to lower values above this level. Because of the relatively low total numbers of needles recovered, changes in individual species are regarded as less significant than the overall decline. Currently the lake lies at the border of the alpine parkland and krummholz zones of tree growth. Although there are trees close to the lake, needles are sparse in the upper 20 cm of lake sediments relative to the lower horizons. Therefore the higher needle concentrations in the lower half of the core are interpreted as indicative of higher treeline. Such dramatically greater needle concentrations suggest dense coniferous growth around the lake, perhaps approaching closed canopy forest. It is uncertain whether the minimum in needle concentrations between 80 and 90 cm depth is due to real change in forest conditions, or whether it is simply a reflection of variation in preservation of needles.

On microscopic examination many of the needle fragments were found to be charred (Fig. 4D). The pattern of charring of the needles is interpreted as representative of the incidence of wildfire within the lake catchment. Assessments of fire history are typically made using counts of microscopic charcoal (Patterson *et al.*, 1987). Microscopic charcoal

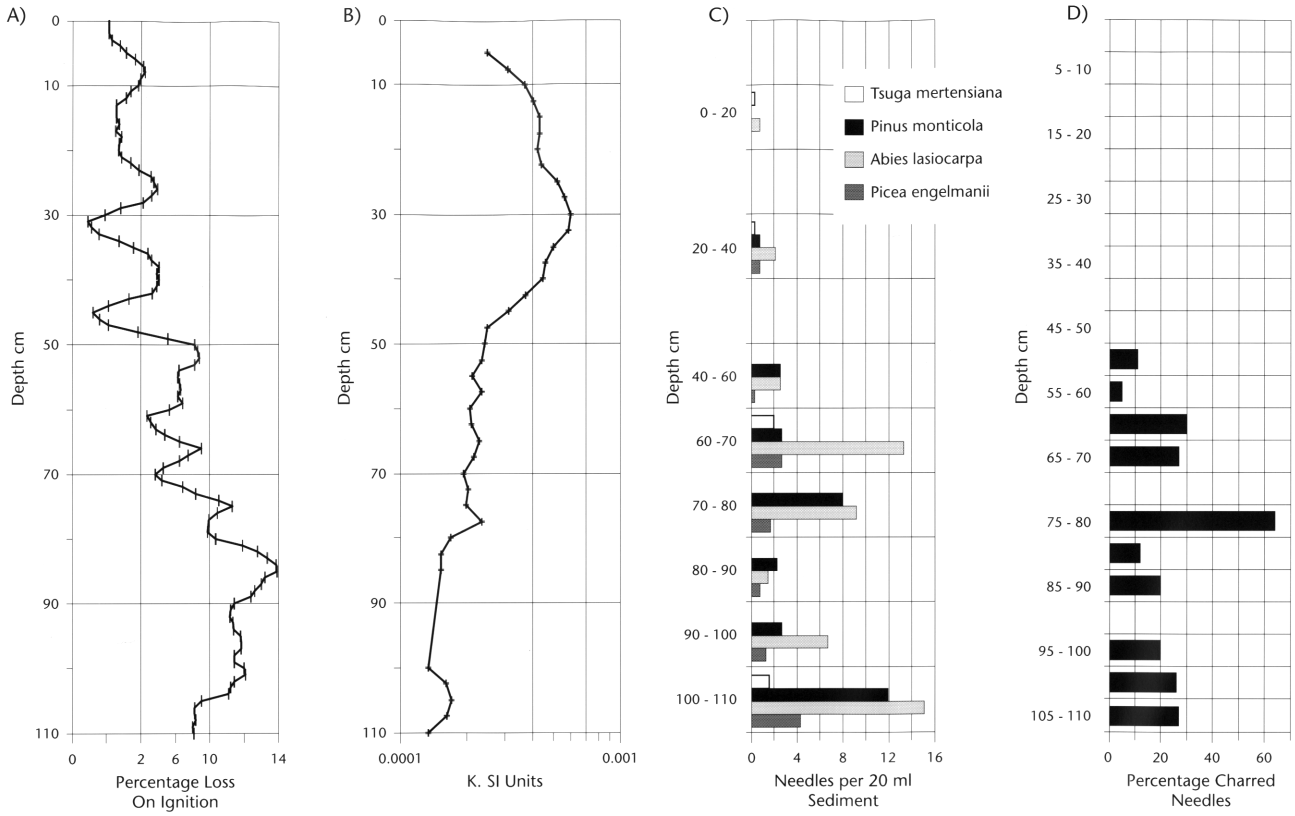

FIGURE 4. A) Five point moving average loss on ignition, Core BD4A. B) Magnetic susceptibility, Core BD4A. C) Concentrations of conifer needle macrofossils, Core BD4A. D) Percentage of conifer needle macrofossils with apparent charring, Core BD4A.

Carotte BD4A. A) Perte au feu : moyenne mobile de 5 points ; B) sensibilité magnétique ; C) concentrations de macrofossiles d'aiguilles de conifères ; D) pourcentage de macrofossiles d'aiguilles de conifères montrant des signes de carbonisation.

(soot) is well dispersed by wind during wildfire. Therefore such counts presumably record a regional fire history. Assessment of charred needles should identify a local signal, in the same way that the needles provide a picture of local vegetation. Charred needles are present in the sediments at all horizons below 55 cm. Warmer summer temperatures or lower precipitation, and an increase in the frequency of convectional thunderstorms during this period would enhance the likelihood of wildfire. However the observed pattern may also be a function of vegetation type at the site, because fire may not spread easily into the subalpine parkland zone where trees are more dispersed. There is a significant peak of charred needles in the sediment at 75 - 80 cm. This peak may represent a single fire. The observation of a small peak in the magnetic susceptibility curve at this level supports this conclusion since wildfire has been shown to enhance the magnetic mineral content of topsoil (Rummery, 1983). The lower percentages of charred needle fragments at other depths most likely represent a background level of charred fragments from previous fires, washed in from soil storage.

SURFACE POLLEN DATA

Figure 5 presents the results of pollen analysis of the surficial sediment samples. This percentage diagram exhibits little elevational zonation of pollen deposition which is perhaps unsurprising, given the difficulties in interpretation of percentage pollen data in mountainous areas (Kearney, 1983; Beaudoin, 1986, Solomon and Silkworth, 1986; Fall, 1992). One pattern emerges, at most sites between 1990 and 2020 m altitude, higher values of Ericaceae pollen are recorded. Associated with these are relatively low values of the principal coniferous pollen types. The high Ericaceae values may simply be a function of very local pollen production, reflecting microtopographic control on plant distribution. However, the principal ericaceous shrubs in the area are *Cassiope mertensiana* and *Phyllodoce glanduliflora*. These are most abundant in a relatively well defined region of well drained areas downslope of the lake. The explanation for the pattern of pollen deposition may therefore lie in a phenomenon identified by Frenzel (1969). He noted that the ratio of non-arboreal pollen to arboreal pollen was highest at treeline. Above treeline, low local production is swamped by up-valley transport of tree pollen, whereas in the meadows and alpine parkland at or just below treeline, local production is enough to depress the percentage of arboreal pollen. The

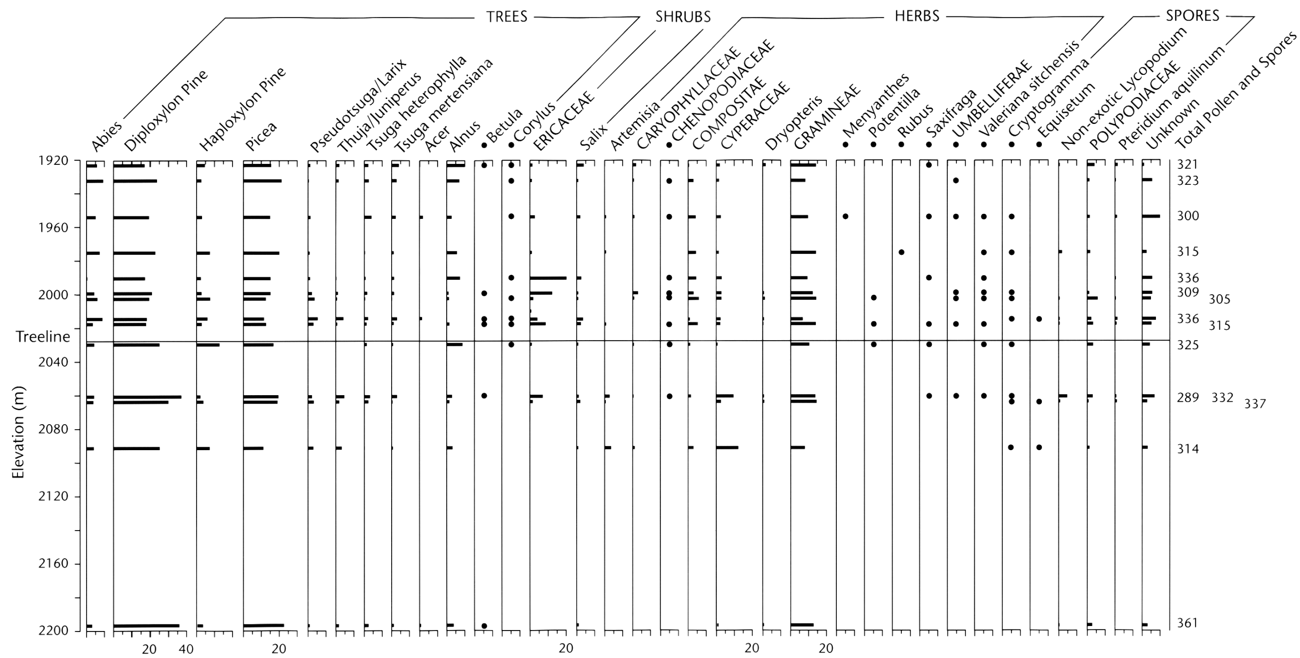

FIGURE 5. Blowdown Lake catchment, percentage pollen data from surface sediment samples.

Données des pourcentages polliniques à partir des échantillons de surface, bassin versant du Blowdown Lake.

data from the Blowdown catchment may therefore be indicative of depression of percentage values of conifer pollen by high local production of ericaceous pollen just below treeline. It appears that the percentage pollen data from the surface samples offer little prospect of quantifying shifts in treeline elevation because of "swamping" (Kearney, 1983) of the signal by lowland pollen.

POLLEN RATIOS

In an attempt to quantify the relation between pollen deposition and elevation, ratios of treeline species pollen to background extralocal pollen types were calculated following the methods of Maher (1963, 1972). Ratios calculated were *Abies/Pinus* (diploxylon) and *Picea/Pinus* (diploxylon). Theoretically, the decline in pollen deposition away from treeline should be exponential. Therefore a linear relation is expected between elevation and the logarithm of pollen ratio. This relation is illustrated in Figure 6. The point at 1987 m marked by the open box on the *Abies/Pinus* diagram is an outlier containing only two *Abies*grains. It is eliminated from the statistical analysis of this plot. The standard errors of lines fitted through these points by linear regression are high. The ratios cannot therefore be used to quantify minor changes in treeline elevation. However a consistent trend may be identified in Figure 6. Lesser pollen ratios generally correspond with higher elevation sites. Downcore variability in pollen ratios can therefore be interpreted in terms of the site's position with respect to treeline. Lesser pollen ratios indicate the site was relatively higher above treeline, i.e. treeline was lower. The pollen ratios therefore appear to offer a reliable qualitative indicator of changes in treeline elevation.

BLOWDOWN LAKE POLLEN ANALYSIS

PERCENTAGE DATA

Figure 7 is the percentage pollen and spore diagram from Blowdown Lake. The whole record is dominated by conifer pollen, especially *Pinus.* The pollen assemblages throughout the core are not radically different from those of the surface samples. This implies that there have been no major changes in the vegetation composition of the extra local region over the period represented by the core. Three local pollen zones (BD. 1 to BD. 3) have been defined by visual inspection. The three zones are characterised below.

Pollen Zonation

BD. 1 This zone is marked by large values of coniferous pollen types. Diploxylon Pine and *Picea* fluctuate at close to 20 % whilst *Abies* comprises around 10% of pollen and spores. *Acer* is represented by a continuous curve throughout most of the zone. Haploxylon pine (*P. monticola* or *P. albicaulis*) values are 5-10% at the base of the zone but decline to a minimum of 3% in the upper half of the zone. The upper boundary of the zone is marked by declines in the *Pinus* and *Picea* curves.

BD. 2 Zone 2 is characterised by lesser values of coniferous pollen types. *Picea*pollen declines from the base of the zone reaching a minimum around 8%. *Abies*pollen percentages remain large at the base of the core but decline to less

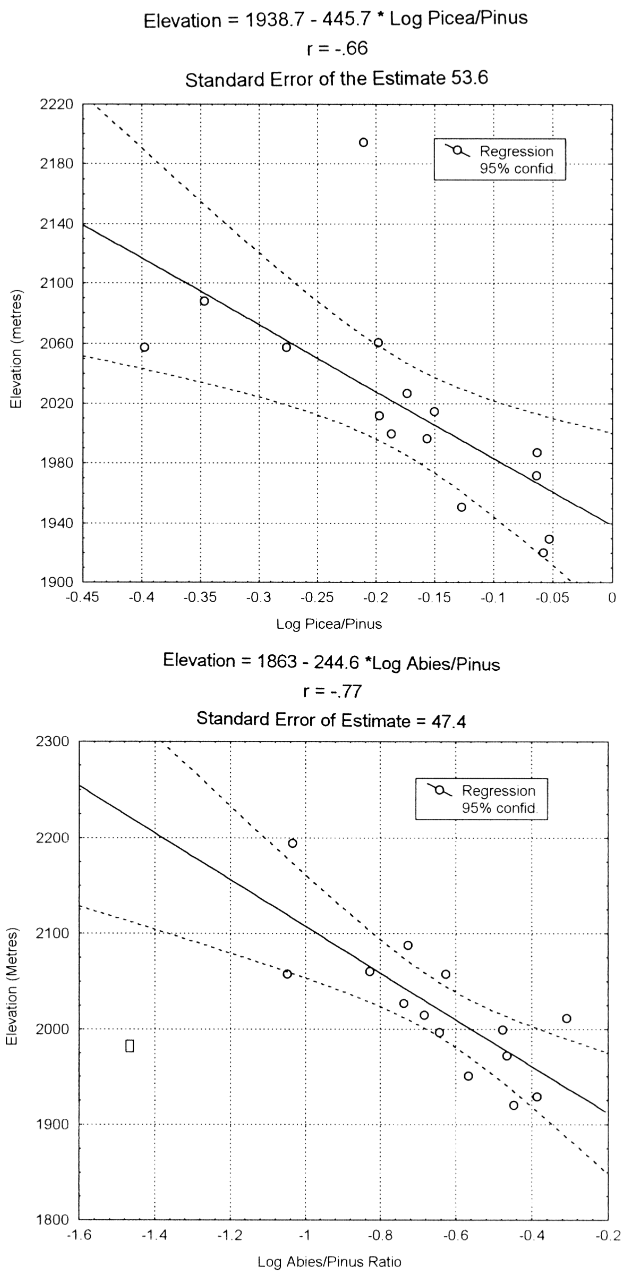

FIGURE 6. Relations of pollen ratios to elevation, Core BD4A.

Carotte BD4A : rapports entre les taux polliniques et l'altitude (carotte BD4A).

than 5% before recovering in the upper part of the zone. Maxima of *Alnus,* Ericaceae*, Salix* and *Pteridium* pollen occur in this zone. The upper zone boundary is marked by decline in pollen percentages for *Alnus*, Ericaceae, and *Salix*.

BD. 3 Zone 3 is marked by a return to larger values for coniferous pollen types. *Pinus* and *Picea* increase, although *Abies* declines from initially large values. Haploxylon pine pollen is reduced in this zone whilst *Tsuga heterophylla* reaches its greatest values at around 5%.

Interpretation of Percentage Pollen Data

Zone 1 spans 110 - 75 cm in core BD4A and therefore approximates the period of higher treeline suggested by the non-palynological evidence (depths 110 - 85 cm). Large percentage representation of *Picea* and *Abies* pollen support this interpretation. 5 to 10 percent *Abies* pollen is a similar value to that recorded in the lowest altitude surface pollen samples from dense subalpine forest.

Zone 2 spans 75 cm to 35 cm depth. Low percentages of *Picea* throughout the period suggest a retreat in treeline. Lower values of *Abies* support this interpretation, although the pattern is less clear. *Salix,* Ericaceae*,* and *Alnus* are common species of the sub-alpine parkland zone at treeline. If treeline retreated, causing a transition in vegetation around the lake from sub-alpine forest to parkland, an increase in these species would be expected. It has already been noted that currently, high Ericaceae pollen percentages depress representation of coniferous pollen types in the alpine parkland zone downslope of the lake. Peak values of Ericaceae*, Alnus,* and *Salix* in zone two therefore provide further indication of treeline retreat during this period.

The peak in *Pteridium* spore percentages during this time period is difficult to interpret. Currently *Pteridium* does not grow at the site. The species is an early coloniser of burnt areas, and therefore indicates that fire is an important component of local ecology. If the *Pteridium* spores were of local provenance it would suggest increasing fire frequency during this period. Treeline was apparently retreating, at this time indicating cooler temperatures. Treeline retreat would ultimately reduce the fuel supply for wildfire but it is possible the *Pteridium* signal indicates a temporary increase in fire activity as dead snags burnt. However, the evidence from charred conifer needles suggests decreased fire frequency above 50 cm, and so does not support this interpretation. An alternative explanation of the *Pteridium* peak is that it represents secondary remobilisation of the spores. Birks and Birks (1980) note that spores are rich in sporopollenin, and are therefore differentially preserved in soils. It has already been suggested that rates of soil erosion may have increased during this period. The peak in representation of *Pteridium* spores may therefore represent inwash of preserved spores from eroding forest soils. However the *Pteridium* grains did not show the obvious degradation which can be associated with reworked spores (Hall, 1981). The interpretation of the *Pteridium* peak therefore remains open.

Zone 3 covers the depths from 35 cm to the surface. The nature of the percentage pollen diagram during this period is similar to that of zone 1 with high *Picea* and *Abies* pollen percentages. However non-palynological evidence suggests that rather than a return to high treeline, this period is marked by a continued cooling of climatic conditions. The

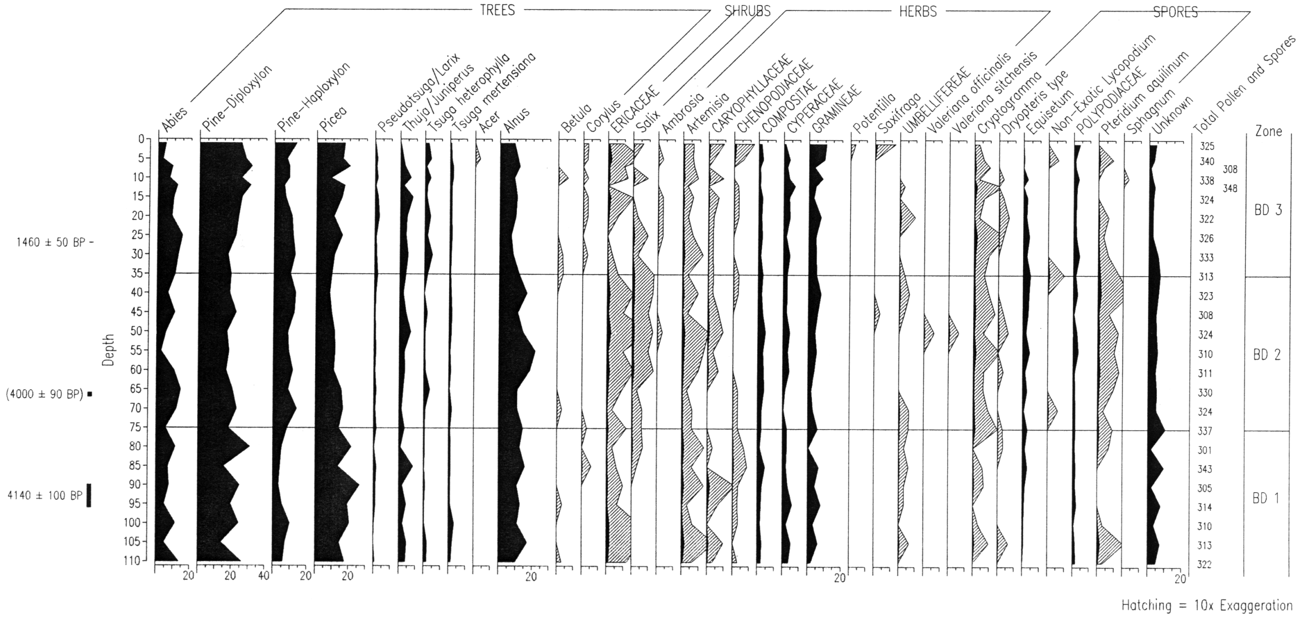

FIGURE 7 Percentage pollen diagram. Pollen sum is of all terrestrial pollen and spores, Core BD4A.

Carotte BD4A : diagramme de pourcentages polliniques. La somme pollinique comprend tous les grains de pollen terrestres et les spores.

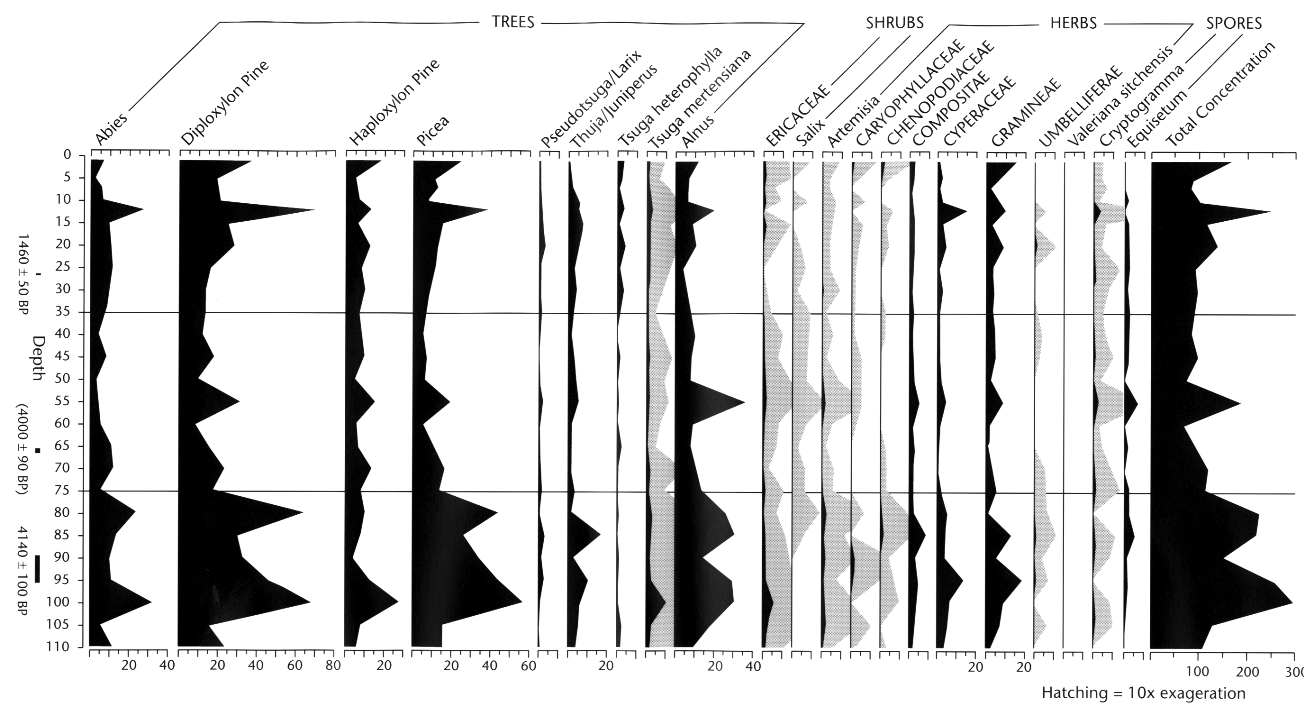

FIGURE 8 Total pollen concentration, x 10^3 grains/cm^3. Core BD4A.

Carotte BD4A : diagramme de concentration pollinique (x 10^3 grains/cm^3).

zone 3 pollen spectra are therefore interpreted as representing sub-alpine/alpine conditions similar to those at the lake today. Low local pollen production by krummholz, grasses, and alpine herbs is therefore 'swamped' (Kearney, 1983) by up valley transport of lowland coniferous pollen. Surface pollen samples from the lake contain high percentages of conifer pollen, despite being above present treeline.

Tsuga heterophylla pollen reaches its highest percentage in zone 3. This species is not present at the site today, but grows at lower elevations. *Tsuga heterophylla* is a component of the wet forests of the coastal zone, and is uncommon in dry interior forests. The site lies on the coast-interior ecotone. The increase in *Tsuga heterophylla* pollen is thus interpreted as indicating a shift to wetter conditions in the lower valley.

POLLEN CONCENTRATION DATA

Figure 8 illustrates pollen concentration data for selected taxa. The pattern of pollen concentration change is similar to the structure of the percentage pollen diagram. However the increase in coniferous pollen in zone 3 is less apparent. This may support the assertion that this apparent increase is an artefact of the percentage pollen diagram. Alternatively, it may simply be a reflection of increased sedimentation rates during the period represented by zone 3. The transition from high to low tree pollen values between zones 1 and 2 is emphasised in the concentration diagram. Again this could be a function of changing sedimentation rates. However, it is suggestive of a shift in vegetation from forest, to less productive sub-alpine shrubs and herbs.

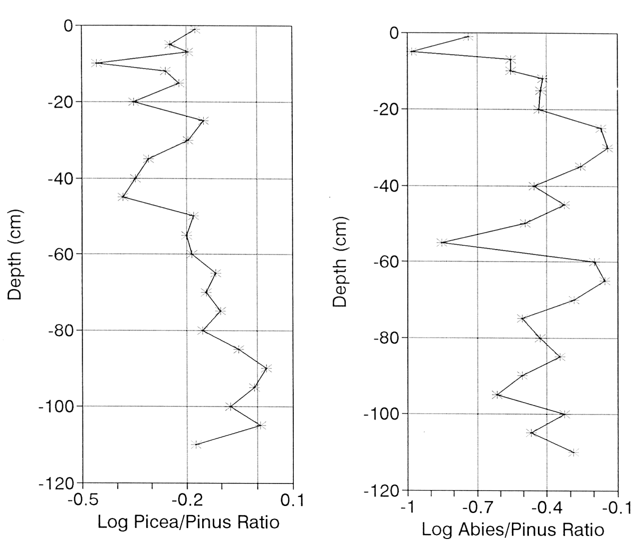

FIGURE 9. Downcore trends in pollen ratios, Core BD4A.

Carotte BD4A : courbes des taux polliniques dans la partie inférieure de la carotte .

POLLEN RATIOS

Figure 9 illustrates downcore variation in the *Picea/Pinus* and *Abies/Pinus*ratios. The general pattern of change in the *Picea/Pinus* ratios is greater values below 80 cm, a transitional period between 80 and 50 cm, and lesser values above 50 cm. There is some pattern apparent in the curve in the latter period. small values between 50 and 35 cm are interrupted by a brief return to larger values between 35 cm and 20 cm. Another period of fluctuating lower values succeeds this above 20 cm. The pattern of high treeline, a transitional period, and then lower treeline is the same pattern identified from sedimentological, macrofossil, and pollen percentage evidence. This strong qualitative similarity provides good support for the assumption that the *Picea/Pinus* ratio is a useful proxy measure of changing treeline. In addition, the structure of the curve during the period of lower treeline suggests that a record of treeline fluctuation in response to Neoglacial climatic deteriorations may be preserved at the site.

Inconsistencies in the pollen ratios

The pattern of downcore variability in the *Abies/Pinus* curve is somewhat different. From the base of the core to 80 cm depth, values are relatively constant. Two minor peaks register at 60-70 and 25-35 cm. The only clear decline occurs above 30 cm. The *Abies/Pinus* curve therefore suggests that treeline remained relatively constant through the period represented by the core, declining only relatively recently.

Consideration of the life history of *Picea engelmanii* and *Abies lasiocarpa*suggests a possible explanation of the apparent inconsistency of the records. At treeline, *Abies lasiocarpa* readily reproduces vegetatively by layering, in contrast *Picea engelmanii* reproduces primarily from seed (Earle, 1993). The responses of the two species to a climatic deterioration will therefore be distinct. Once conditions at treeline decline to the point that seedling establishment and survival are unlikely then *Picea* will not be replaced and will retreat to lower elevations. In contrast, *Abies* may continue to reproduce vegetatively. Continued pollen production by krummholz *Abies* would account for the delayed decline in treeline indicated by the *Abies/Pinus* pollen ratio curve. The eventual decline apparent in this curve may represent a further climatic deterioration reducing krummholz pollen production or alternatively killing remaining trees at higher elevations.

The patterns of modern pollen deposition shown in Figure 6 support this hypothesis since the slope of the *Picea/Pinus* regression line is greater than that of the *Abies/Pinus* line. If this pattern were a function of transport of pollen the reverse pattern would be expected since the *Abies* grains are larger. Therefore the most likely explanation for the pattern is continued pollen production by the *Abies* krummholz above treeline. The observed pattern of *Abies* and *Picea* around Blowdown Lake supports the above analysis. The krummholz islands above the lake are almost exclusively *Abies*. Where *Picea* is found it is commonly as small single trees rather than in tree islands, suggesting production from seed. In the parkland zone *Picea* occurs as occasional individuals whereas in the closed canopy forest it is more common. It is therefore likely that at this site the *Picea/Pinus* ratio is a better indicator of altitudinal shifts in the boundary between erect trees and krummholz forms than the *Abies/Pinus* ratio.

Comparison of the two ratio curves in Figure 9 shows that during the *Picea* maximum 110-80 cm the *Abies* curve is depressed. The first major peak in the *Abies/Pinus* curve occurs as the *Picea/Pinus* decline is initiated. The reason for the out of phase behaviour of the *Abies/Pinus* ratio is unclear. It may be that the layering of *Abies* confers a competitive advantage on it during cooling episodes. Because *Abies* is common in the krummholz form, and there is no way to remove krummholz pollen from the record interpretation of the *Abies*record in terms of treeline may not be possible.

Although the calibration of Figure 6 is not sufficiently precise to allow confidence in detailed quantitative estimates of treeline fluctuation it is reasonable to use the surface samples to estimate the approximate magnitude of the changes. The *Picea/Pinus* ratios below 85 cm in the core are greater than those of the lowest elevation modern surface samples. It would appear therefore that in the period represented by the lowest part of the core treeline was more than 100 m higher than at present. Assuming that the treeline is temperature controlled and using a local lapse rate of 0.7°C/100 m this suggests mean July temperatures at least 0.7°C above those of the present.

PALAEOENVIRONMENTAL CHANGE AT BLOWDOWN LAKE

In topographically complex areas comparisons of multiple lines of evidence are more than usually important for environmental reconstruction. What emerges from such a comparison at Blowdown Lake is a consistent picture of environmental change, presented by both palynological and non-palynological evidence. The evidence for the major periods of environmental change is discussed below. The similarity of sedimentation rates calculated between the two ^{14}C dates suggests that average rates may have been relatively constant. This may be due in part to considerable compression of the core during extrusion which would be concentrated in the unconsolidated upper sediments. On the basis of these observations a linear interpolation between the acceptable radiocarbon dates was adopted. The tentative dates given in the following discussion are based upon this interpolation.

PRIOR TO 3400 BP

Before 3400 BP (below 75 cm depth) pollen and macrofossil evidence suggest that treeline was higher than at present and that dense forest probably surrounded the lake. LOI is relatively high during this period which probably reflects the large supply of organic material to the lake from the forested catchment. Low magnetic susceptibility values may result from the organic nature of the sediment, however, they likely also reflect lower input of mineral material to the lake. This implies less catchment erosion and is consistent with stable vegetated slopes. Charred needles suggest a major fire at around 3600 BP. It is possible that this fire hastened treeline retreat by removing live trees from the zone where they may have survived, but regeneration was unlikely. The evidence of fire slightly postdates the first indications of treeline retreat in the pollen record. The fire may therefore have burned in the parkland zone burning dead snags and tree islands.

3400-2400 BP

From 3400 BP until around 2400 BP (75-50 cm depth) percentage pollen evidence suggests lower treeline. Similarly the *Picea/Pinus* ratio declines whilst the *Abies/Pinus* ratio remains stable. This probably represents an opening up of the forest around the lake with retreat of *Picea*. *Abies* remains and may even expand in the krummholz form. Gradual increase in magnetic susceptibility, and declining LOI imply a transitional period, characterised by either lower organic inputs to the lake, higher mineral input, or both. This suggests increasing erosion in the catchment.

2400 BP TO THE PRESENT

The period from 2400 BP (50 cm depth) to the present witnesses a fluctuating lower treeline. *Picea* pollen ratio data identify two periods of low treeline. The *Abies* ratio data suggest that the during the later of these periods the elevation of the krummholz zone may also have been depressed. The other proxy records do not detect these minor fluctuations. However minima of macrofossil concentrations, more minerogenic sediment, thicker graded sand deposits, high magnetic susceptibility values, and the cessation of deposition of charred needles, all point to lower treeline, and increases in erosion. The presence of dropstones in sediments above 50 cm depth suggests increased avalanche activity (Luckman, 1975) due to greater snow accumulation on the catchment slopes during this period.

CORRELATION WITH EARLIER WORK

Having established a chronology for the evidence of environmental change at the Blowdown Lake site it is possible to evaluate the extent to which the changes in this pollen record correlate with periods of Neoglacial advance identified by Ryder and Thomson (1986).

As noted the graph of *Picea/Pinus* ratio, which is assumed to be a proxy for changing treeline elevation, shows some pattern in the period since 2400 BP (50 cm depth). The two periods of apparently lower treeline than present date by interpolation at 2400-1500 (50-28 cm) and 1200-200 BP (22-5 cm). These periods are reasonably consistent with the mid and late Neoglacial advances identified by Ryder and Thomson (Tiedemann Phase, 3300-1900 BP and the Little Ice Age, 900-100 BP). The maximum of the earlier Tiedemann glacial phase was at 2500 BP. The time difference between the Tiedemann phase and the earlier period of low treeline may be a function of a lagged treeline response to climatic change or simply due to error in the interpolated dates.

DISCUSSION

The stated aim of this paper was to produce a palynological record of Neoglacial climate change. The results suggest that simple sensitive alpine/subalpine sites can provide such a record. However, because of the complexities introduced by pollen transport across the subalpine ecotone, interpretation of the percentage pollen diagram in terms of treeline shifts was not possible without reference to parallel lines of evidence. Maher (1963,1972) suggested that pollen ratios provide a more robust measure of shifting treeline. The evidence from Blowdown Lake shows that the sensitivity of this technique is highly dependent on selection of appropriate ratios. The differing patterns of *Picea* and *Abies* to *Pinus* ratios suggest that careful consideration of the autecological responses of tree species to climatic stress is required for the interpretation of ratio data. With these provisos it appears that alpine pollen records can provide useful information on the nature of Neoglacial climate changes. The data appear to confirm the hypothesis of Souch (1990) that the absence of evidence of Neoglacial climate fluctuations in the pollen record of southern B.C. is a function of the largely lowland nature of the record. The apparent correlation between periods of lower treeline and phases of Neoglacial ice advance suggests that these advances were at least partly controlled by reduced ablation due to lower summer temperatures.

The *Pinus/Picea* ratios from Blowdown Lake appear to record the Tiedemann and Late Neoglacial phases and are therefore consistent with the regional pattern of climate change in the second half of the Neoglacial demonstrated by Ryder and Thomson (1986). The observation of correlative fluctuations in the elevation of temperature sensitive treeline confirms the association of the Neoglacial phases with lower summer temperatures.

Conditions warmer than present at the site until 3400 BP are of particular interest. Hebda (1995) has suggested that the onset of full Neoglacial conditions in many areas of B.C. was delayed until after 4500 BP. The Blowdown Lake record provides some evidence that this pattern extends to the Coast Mountains.

Although the results of this study do not allow a continuous quantification of palaeotemperature the approach is promising. Identification of further treeline sites with abundant sites for sampling surface pollen and a long sedimentary record, may allow quantification of palaeotemperatures through more detailed calibration of pollen ratio/treeline elevation relations. Due to the complexity of interpreting pollen evidence from mountainous regions it is important that parallel lines of evidence establish that pollen ratio fluctuations are related to treeline shifts. Where these conditions are met, shifts in temperature controlled treeline may be interpreted as a continuous palaeotemperature record.

FIGURE(S)

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