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Holocene Timberline Fluctuations in Jasper National Park, Alberta

Abstract. *Pollen, fossil logs, and macrofossils from three high-elevation sites in the Maligne Range, Jasper National Park, Alberta, provide the first detailed record of timberline fluctuations in the Canadian Rockies during the last 8700 years. Timberlines were much higher than at present between 8700 to 5200 years ago but oscillated significantly in elevation, with a major episode of timberline recession punctuating two periods of high timberline between about 6700 to 5900 and about 8700 to 7000 years ago. Since 5200 years ago, regional timberlines have generally receded with perhaps brief reversals, reaching their lowest recorded positions sometime after 500 years ago.*

Past fluctuations in the alpine timberline have proved to be sensitive indices of Holocene climatic changes in several areas of North America (*1*). We report the results of what we believe to be the first detailed investigation of Holocene timberline changes in the Canadian Rockies based on pollen, fossil logs, and macrofossils recovered from three sites above the present timberline in the Maligne Range, Jasper National Park, Alberta. These results provide a clearer definition of the Holocene climatic history of this area, particularly the Hypsithermal, than has been possible before now and are compared with data for other sites in the North American Cordillera.

The Maligne Range forms the interfluve between the Athabasca and Maligne rivers (Fig. 1) and consists of clastic Cambrian and Precambrian rocks rising to 2500 to 3000 m above sea level. Climatic data are sparse (*2*). Rainfall increases with elevation and ranges from 500 to 1000 mm per year (1300 to 5000 mm of snowfall). The mean annual temperature for Jasper (elevation, 1061 m) is 2.8°C, with July and January means of 15.2°C and −12.2°C, respectively. The Maligne and Athabasca valleys lie primarily within the subalpine forest zone and are dominated by varying proportions of *Picea engelmanni* Parry (Engelmann spruce), *Abies lasiocarpa* (Hook.) Nutt. (subalpine fir), and *Picea glauca* (Moench) Voss (white spruce). The summits and upper reaches of valleys in the Maligne Range are mantled by alpine tundra. All the sites reported here lie above present timberlines (Fig. 1) (*3*) and are surrounded by heath (*Cassiope* spp.) tundra communities intermixed with stands of *Salix arctica* Pall (arctic willow). Occasional dwarf subalpine fir (*Abies lasiocarpa* krummholz) occurs in the vicinity of the Watchtower Basin site.

Pollen cores recovered from the Watchtower Basin and Excelsior Basin sites (*4*) provide the most complete and continuous records of past timberline oscillations in this area. We reconstructed the direction and magnitude of past timberline changes from ratios of selected pollen taxa, using regression equations derived from the relation between altitude and modern surface samples (Fig. 2) (*5*). When plotted against eleva-

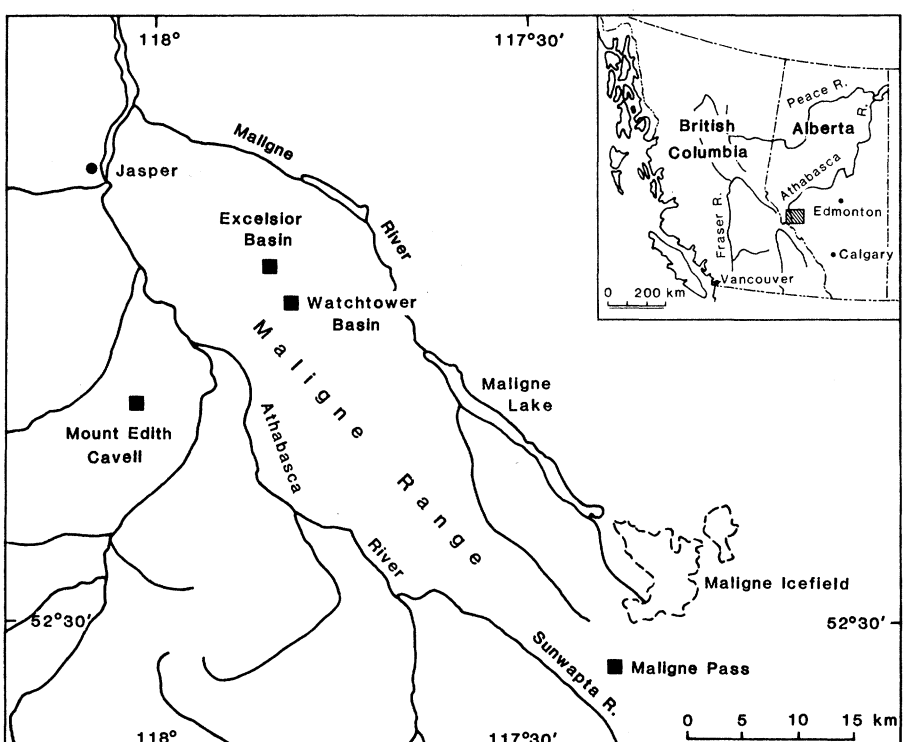

Fig. 1. Sketch map of a part of Jasper National Park, showing the site locations.

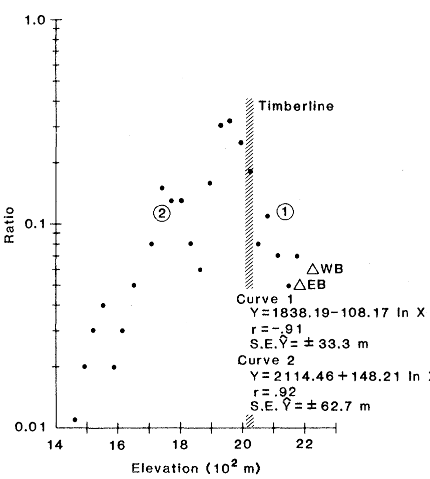

Fig. 2. Elevational changes in *Abies/Pinus* pollen ratios (dots) from modern surface samples collected on Mount Edith Cavell, approximately 10 km south of Jasper. The regression line defined by curve 1 includes all samples above the timberline; curve 2 is based on all samples below the timberline; r = correlation coefficient; S.E.$\hat{y}$ = standard error of the estimated value of y. *Abies/Pinus* ratios (triangles) for surface samples of the Watchtower Basin (*WB*) and Excelsior Basin (*EB*) cores are shown for comparison.

Table 1. Characteristics of fossil logs recovered from sites above tree lines.

Sample No.	Genus	Length (cm)	Diameter (cm)	^{14}C date (years)	Number of rings	Mean ring width (mm)	Comments
				Watchtower Basin			
W1	*Picea*	244	11 (base)	8060 ± 90 (GSC-2615)	120	0.46	Complacent
W2	*Picea*	30	40*	7910 ± 70 (GSC-3226)	~ 60	~ 0.33	
W3	*Picea*	50	8	8770 ± 80 (GSC-3195)	31	1.32	Very complacent
				Maligne Pass			
MP1	*Abies*	470†	22	5920 ± 100 (BGS-566)	91	1.12	Tilted stem
MP2	*Abies*	353†	13	5260 ± 70 (GSC-3147)	150	0.56	

*Estimated from curvature of rings. †Rootstock attached.

tion on semilogarithmic paper, the *Abies*/*Pinus* pollen ratios exhibit two linear trends (*6*), increasing up to the vicinity of the timberline and thereafter decreasing above the tree line. Using elevation as the dependent variable, we determined by least squares that elevational changes in these ratios (X) are best approximated by Eq. 1

$$Y = 1838.19 - 108.17 \ln X \quad (1)$$

above the timberline and by Eq. 2

$$Y = 2114.46 + 148.21 \ln X \quad (2)$$

below the timberline.

Past timberline changes are expressed as variations in site "apparent elevation" (*6*). Apparent elevation changes are based solely on Eq. 1. Although a particular *Abies*/*Pinus* ratio may be replicated above and below timberline, both pollen sites are well above the general tree line and none of the fossil pollen ratios exceed the maximum ratio value near timberline. For sites above the present timberline a lower apparent elevation indicates that the site was closer to the timberline than it is at present—that is, timberline advanced toward the site. Conversely, higher apparent elevations indicate that the timberline had receded down-valley relative to its present position. Apparent elevation curves for both sites are shown in Fig. 3. Dating control for the curves is based on the radiocarbon dates shown, the Mazama tephra [~ 6600 years ago (*7*)], and interpolation from other dated sedimentary records at the sites. These data indicate that the basal peats of these pollen cores date from ~ 8100 (Watchtower Basin) to 8500 (Excelsior Basin) years ago.

The apparent elevation data indicate that timberlines were much higher than at present between ~ 8500 and 5900 years ago (*8*). Two major periods of high timberline may be identified dating from ~ 8500 to 7000 and ~ 6700 to 5900 years ago in the more detailed Watchtower Basin curve. These are separated by a brief but well-marked period of timberline recession culminating ~ 6900 years ago when the timberline approached its modern limits. The sharp rise in apparent timberline elevations at both sites after ~ 5900 years suggests a substantial lowering of timberline elevation. Peat accumulation was much slower (~ 0.5 to 1.0 cm per century) at both sites during the late Holocene. The better-dated Watchtower Basin record indicates timberlines close to present levels until ~ 1600 years ago. Thereafter considerable retreat occurred, punctuated by two brief reversals ~ 1000 and 500 years ago. Timberlines reached their lowest recorded elevation sometime after 500 years ago.

The palynologic evidence of higher timberlines between ~ 8500 and 5900 years ago is confirmed by the presence of spruce and fir needles in this interval of the Watchtower Basin core (Fig. 3) and by logs recovered from this site and Maligne Pass (Table 1). The dimensions of these logs, complacent ring width patterns, and the presence of rootstocks in some cases indicate that they were well-developed standing trees, not krummholz, and were growing on or adjacent to the bogs under quite favorable conditions. Data for the oldest log from the Watchtower Basin site (W3, Table 1) suggest that the initial timberline advance predated the recovered pollen records.

The well-documented strong correlations of timberline elevations with certain summer isotherms (commonly the July 10°C isotherm) have long favored a temperature-related threshold as the major control of timberline elevation (*9*). We would discount fire as a probable cause of the trends in Fig. 3 as there is little evidence from the logs, the sedimentary record, or the age characteristics of the present vegetation cover (*10*) to support frequent major fire activity. Extended timberline fluctuations such as those demonstrated at these sites must have been related to climatic conditions. The data in Fig. 3 suggest a maximum displacement of ~ 200 m for timberlines during the last 8100 years.

The inferred postglacial timberline history of the Jasper area parallels available Holocene timberline records for other sites in the Cordillera (*1*). A mid-Holocene timberline high stand, occurring between 9000 and 4500 years ago depending upon locale, is generally well documented in these chronologies and provides the most compelling paleobotanical evidence for a mid-Holocene warm period or Hypsithermal. This evidence contrasts with many Cordilleran pollen profiles, particularly from the Northern Rockies, where the signature of a Hypsithermal is often equivocal or

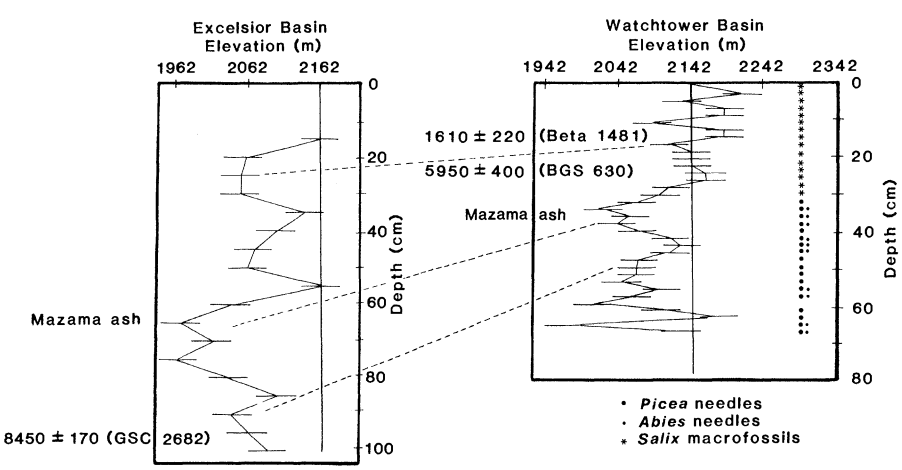

Fig. 3. Changes in the apparent elevation of the Watchtower Basin and Excelsior Basin sites. Vertical lines drawn through the curves indicate the present apparent elevations of the sites. The horizontal bars on the curves are the confidence limits (.95 level) of the reconstructed elevational changes. Dashed lines indicate equivalent peaks in the curves. We corrected the *Abies*/*Pinus* ratios for the presence of grains of the high-altitude pine species *Pinus albicaulis* by subtracting from the unidentified pine sum the proportion of these grains found in the identified sum.

absent (*11*). The onset of generally cooler summers after 4000 to 5000 years ago, indicated by the overall decline in timberline elevations (*12*), is compatible with the Holocene glacial record of the Cordillera, which shows an increasing incidence of glacial activity culminating in the "Little Ice Age" advances of the last few centuries (*13*).

The Hypsithermal remains one of the most striking features of late Quaternary climate, and evidence is mounting in support of rapid and complex changes in temperatures during this period in western North America. Archaic settlement data from the Colorado Front Range (*14*) indicate major discontinuities in the settlement record of this area between ~ 7000 and 6500 years ago and ~ 6000 to 5500 years ago, perhaps as a result of prolonged severe droughts. Analyses of the annual rings of fossil bristlecone pine snags from New Mexico (*15*) reveal major fluctuations in atmospheric ^{14}C between ~ 8000 and 5000 years ago, with a substantial departure ~ 7500 years ago. These variations in atmospheric ^{14}C are thought to be proxy data for fluctuations in solar activity (*16*) and therefore possibly for climatic changes. We believe that the complex and apparently episodic oscillations in summer temperatures exhibited by the Jasper timberline record support the picture of a multiphase Hypsithermal.

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Ages Estimated from a Diffusion Equation Model for Scarp Degradation

Abstract. *The diffusion equation derived from the continuity equation for hillslopes is applied to scarp erosion in unconsolidated materials. Solutions to this equation allow direct calculation of the product of the rate coefficient and the age of the scarp from measurements of scarp morphology. Where the rate coefficient can be estimated or can be derived from scarps of known age, this method allows direct calculation of unknown ages of scarps.*

In the past 25 years many efforts have been made to mathematically model the evolution of hillslopes (*1, 2*). These models are constrained by the diversity and complexity of natural hillslopes and by difficulties in determining the ages of many landforms. Scarps in unconsolidated materials are common landforms that are simpler than other kinds of hillslopes. They often have specifiable initial conditions, and they change fast enough to test the temporal predictions of mathematical models. Recent studies of scarps (*3–6*), especially fault scarps, have produced many measurements of scarp morphology (Fig. 1A). The purpose of this report is to explicitly solve the diffusion equation for scarp boundary conditions and to demonstrate how the solution can be used to estimate scarp age.

Changes in the morphology of scarps in unconsolidated deposits are controlled by transport-limited processes, primarily soil creep, raindrop impact, and slope wash. For these processes the supply rate of loose debris is not a controlling factor, and process rates are generally proportional to powers of the slope distance and the sine or tangent of the slope angle (*2*):

$$S = cx^m \frac{\partial^n y}{\partial x^n} \qquad (1)$$

where S is the rate of downslope transport, c is a rate constant, x is horizontal distance, and y is elevation. For raindrop impact and creep processes, which are the dominant processes on many scarps, $m = 0$ and $n = 1$ are generally accepted (*1, 2*). For slope wash m and n may vary considerably, but in some cases $m = 0$ and $n = 1$ (*7*). Slope wash on the relatively short, steep slopes of scarps seems likely to conform to these values. Where $m = 0$ and $n = 1$ the rate of downslope transport is simply proportional to the surface gradient.

Most models of hillslope evolution are based on continuity considerations and assume no change in density of the surficial material (*1, 2*). This requires that the change in elevation of a point be equal to the difference between the amount of material transported to the point and the amount of material transported away from it, or

$$\frac{\partial y}{\partial t} = \frac{\partial S}{\partial x} \qquad (2)$$

Combining the continuity equation (Eq. 2) with the dependence of downslope transport on surface gradient (Eq. 1 with $m = 0$ and $n = 1$) gives the diffusion equation

$$\frac{\partial y}{\partial t} = c\,\frac{\partial^2 y}{\partial x^2} \qquad (3)$$

This equation is well known as a description of many processes in chemical diffusion, conductive heat flow, and flow through porous media. Equation 3 has also been derived for a variety of slope models (*1, 2*), including several for scarp evolution (*4, 8*). For scarp boundary conditions it has been solved by finite difference methods (*4*) and by analytical methods (*8*) similar to those presented here.

The diffusion equation applied to scarps implies that the change in elevation of a point is proportional to the profile curvature at that point. Thus with time the crest and the toe become round-