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RESEARCH REPORT

DENDROGLACIOLOGICAL EVIDENCE FOR A NEOGLACIAL ADVANCE OF THE SASKATCHEWAN GLACIER, BANFF NATIONAL PARK, CANADIAN ROCKY MOUNTAINS

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ABSTRACT

Seventeen glacially sheared stumps in growth position and abundant detrital wood fragments were exposed by stream avulsion at the terminus of the Saskatchewan Glacier in 1999. The stumps lay buried beneath the glacier and over 5 m of glacial sediment until historical recession and stream incision exposed the 225- to 262-year-old stand of subalpine fir, Englemann spruce and whitebark pine trees. Crossdating and construction of two radiocarbon-controlled floating tree-ring chronologies showed that all the subfossil stumps and boles exposed at this location were killed during a Neoglacial advance of the Saskatchewan Glacier 2,910 ± 60 to 2,730 ± 60 ^{14}C years B.P. These findings support the *Peyto Advance* as a regional glaciological response to changing mass balance conditions.

Keywords: dendroglaciology, floating chronology, Saskatchewan Glacier, Peyto Advance, Canadian Rocky Mountains.

INTRODUCTION

The Neoglacial was initially described as a world-wide glacial event that followed a period during which glaciers were at their Holocene minimum (Porter and Denton 1967). Increased understanding of Holocene glacial activity, however, has resulted in recognition that the Neoglacial is asynchronous, with advances attributed to this period ranging from 8,000 ^{14}C years B.P. (Denton and Karlen 1973) to 3,000 ^{14}C years B.P. (Luckman *et al.* 1993). Within the Canadian Rocky Mountains, the onset of mid-Holocene Neoglacial glacial activity is heralded by cooler/moister conditions *ca.* 4,000 ^{14}C years B.P. (Beaudoin and King 1990; Reasoner and Huber 1999) and is evidenced by trees buried by Boundary Glacier 4,200 and 3,800 ^{14}C years B.P. (Gardner and Jones 1985). Other evidence shows that by *ca.* 3,300 and 2,800 ^{14}C years B.P. glaciers throughout the region were advancing down valley (Luckman *et al.* 1993). Following this advance, most glaciers appear to have retreated up valley and may have only begun to readvance during the well-documented late-Holocene Little Ice Age (LIA) glacial events of the last 900 years (Luckman 1986, 1993, 1995, 2000). The intention of this paper is to discuss the significance of recently exposed ice proximal subfossil stumps and detrital boles at the Saskatchewan Glacier in the Canadian Rocky Mountains (Figure 1).

The Saskatchewan Glacier is the largest outlet glacier of the Columbia Icefield. Located in northern Banff and southern Jasper National Parks (52°06′30″N, 117°15′10″S), the Columbia Icefield straddles the Alberta–British Columbia inter-provincial border and is located within the Main Ranges structural province of the Canadian Rocky Mountains. Folded and thrust-faulted mountains composed of limestones with shale and dolomite

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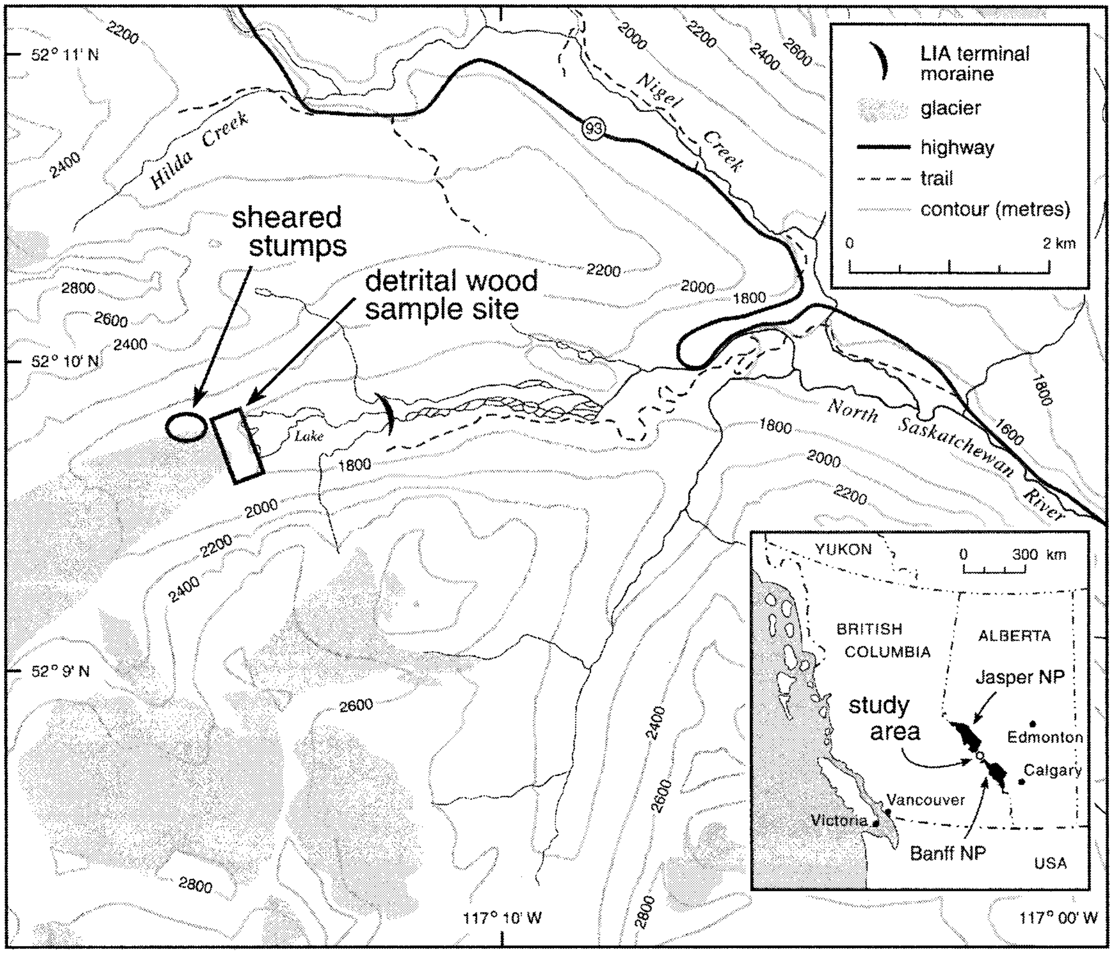

Figure 1. Map of the Saskatchewan Glacier showing the location of the sampling sites.

interbeds dominate the local terrain (Ford 1983). The local relief is greater than 2,000 m. The climate of the area is cool and wet (Janz and Storr 1977), with major cold intervals within the last millennia at *ca.* A.D. 1200–1350, the 1690s, and the 19th Century shown to coincide with local and regional periods of glacier expansion (Luckman *et al.* 1997; Luckman 2000). The vegetation of the Columbia Icefield area is characterized by subalpine forests and expansive alpine tundras (Holland and Coen 1983), with most valley bottoms characterized by Engelmann spruce (*Picea engelmanni*) and lodgepole pine (*Pinus contorta*) forests. Restricted stands of subalpine fir (*Abies lasiocarpa*), whitebark pine (*Pinus albicaulis*) and krumholtz spruce characterize treeline (Luckman and Kavanagh 1998, 2000; Luckman and Youngblut 1999).

The Saskatchewan Glacier flows in a north-easterly direction for *ca.* 10 km through a steep-walled valley that is the source of the North Saskatchewan River (Figure 2). Over the last century the Saskatchewan Glacier has experienced significant downwasting and frontal retreat (Field 1949; Henoch 1971; McPherson and Gardner 1969; Gardner 1972; Robinson 1988). Meltwater currently drains into a proglacial lake close to the terminus (1,710 m a.s.l.) before flowing through a terraced outwash plain.

The LIA behaviour of the Saskatchewan Glacier has been described by Heusser (1956) and Robinson (1998). They record multiple LIA events,

Figure 2. Sheared stumps in growth position protruding from an ice proximal meltwater channel along the northern terminus of the Saskatchewan Glacier in September, 1999. Radiocarbon dates of 2,830 ± 60 (Beta 135586) and 2,870 ± 60 (Beta 135587) ^{14}C years B.P. were obtained from the perimeter of two of the stumps.

including a significant mid-19th Century advance and a less extensive event during the early and middle parts of the 18th Century (Figure 2). Evidence for pre-LIA events comes from detrital wood found on ice proximal outwash deposits at various times over the last two decades (Luckman *et al.* 1993, 1994). The oldest samples date between 3,200 to 2,500 ^{14}C years B.P. (Table 1) and provide circumstantial evidence for an advance equivalent to the Neoglacial *Peyto Advance* (Osborn and Luckman 1988; Luckman *et al.* 1993; Luckman 1993, 1996).

In late-August 1999, a severe rainstorm resulted in stream avulsion along the northeastern flank of the Saskatchewan Glacier snout (117°08′45″N; 52°09′30″W). When first examined in early September, erosion through a 3- to 5-m sequence of glacial outwash and overlying till had exposed 17 sheared stumps rooted within a well-preserved paleosol (Figure 2). A further 29 recently deposited ice-proximal detrital boles/stumps were located 50 to 150 m downstream on the adjacent outwash surface. By September 2000, the meltwater channel had shifted southward and had eroded through 5 m of fluted moraine deposits, exposing 2 additional rooted stumps and flushing an additional 40 detrital boles onto the outwash surface.

METHODS

Dendroglaciology, a subdiscipline of dendrochronology, uses tree-ring methods to study the past movement of glaciers (Luckman 1988; Schweingruber 1988). In recent studies within the southern Canadian cordillera, exposed stumps in growth position have been used to distinguish Holocene glacial advances by crossdating floating tree-ring series to living tree-ring chronologies (*e.g.* Luckman 1995; Smith and Laroque 1996) or by assigning ^{14}C dates to perimeter wood samples (Smith *et al.* 1995; Luckman 1996, 1998).

In this study, cross-sectional discs were collected in 1999 and 2000 from 19 rooted stumps and 69 ice-proximal detrital boles/stumps. After air-

Table 1. Radiocarbon ages of subfossil wood samples from Boundary and Saskatchewan glaciers.

Sample No.	Laboratory No.*	Age ^{14}C years B.P.	Comments
A) Saskatchewan Glacier			
UVTRL 99W07	Beta 135586	2,830 ± 60	Sheared stump, this study
UVTRL 99W24	Beta 135587	2,870 ± 60	Sheared stump, this study
SG8806	Beta 31359	2,880 ± 70	Detrital wood fragment (Luckman *et al.* 1993)
UVTRL 99W31	Beta 135588	2,910 ± 60	Detrital wood fragment in till, this study
SG8807	Beta 29957	2,940 ± 80	Detrital wood fragment (Luckman *et al.* 1993)
Gardner	BGS1369	3,180 ± 80	Detrital wood fragment, J. S. Gardner (Luckman *et al.* 1993)
B) Boundary Glacier			
UVTRL 01-2MB	Beta 160362	3,880 ± 40	Sheared stump, this study
Gardner and Jones	WAT-1183	3,880 ± 60	Peat deposit
Gardner and Jones	WAT-1182	4,050 ± 70	Sheared stump (Gardner and Jones 1985)

*Beta, Beta Analytic, Florida; BGS, Brock University; WAT, Waterloo.

Table 2. Summary statistics of floating subfossil chronologies.

Species	No. Samples	Duration (years)	Correlation with Master[1]	Mean Sensitivity[2]	SSS[3]	Standard Deviation
Subalpine fir	26	225	0.437	0.186	0.888	0.337
Whitebark pine	13	262	0.402	0.176	0.789	0.371

[1] The "correlation with master" statistic is a measure of the common signal within the series and is significant at values greater than ±0.3281 at the 99% confidence interval (Holmes 1999).

[2] Mean sensitivity is the mean percentage change from each measured yearly ring value to the next (Douglass 1936, cited by Fritts 1976). It is viewed as a measure of complacency with a value of 0 indicating little or no variation in ring-width values and 1 indicating extreme ring-width variation or a high sensitivity to change.

[3] The subsample signal strength (SSS) statistic indicates whether there is enough signal in the data to be able to use the series as a predictive tool. An SSS value of greater than 0.80 is considered significantly strong to be used for further analysis (Wigley *et al.* 1984).

drying, the discs were sanded with progressively finer grades of sand paper (100 to 600 grit) to a high polish. Discs that were partially rotted or had missing fragments were soaked in melted paraffin wax to provide additional support. The samples were identified to species using a 40× microscope and a standard reference key (Hoadley 1993). Twenty-two samples were excluded from subsequent analysis, as they could not be identified to species with any certainty.

Floating species-specific tree ring chronologies were constructed using conventional dendrochronological procedures (Stokes and Smiley 1968). A WinDENDRO™ digital tree-ring system (Guay *et al.* 1992) and a Velmex-type stage were used to measure the annual ring increments to the nearest 0.01 mm. Visual comparison of marker years and verification procedures within the COFECHA software program were used to define relative perimeter dates for each sample (Holmes 1999; Grissino-Mayer 2001). The chronologies were standardized with ARSTAN default settings to remove life-cycle growth trends (Cook 1985). Table 2 presents the tree-ring statistics established from 13 subfossil whitebark pine samples spanning a 262-year interval and 26 subfossil subalpine fir samples spanning a 225-year interval.

To ensure that the subfossil wood samples were not of recent origin, they were compared to living tree-ring chronologies collected in close proximity during these and previous studies (Luckman *et al.* 1997; Carter *et al.* 1999; Bachrach *et al.* in press). After these crossdating attempts failed, three subsamples were submitted for standard radiocarbon analysis. Two were near-perimeter tree-ring sequences from stumps found in growth position (UVTRL 99W07, 27 annual rings and UVTRL 99W24, 55 annual rings; see Figure 2) and one was a near-pith sample from a fragmented bole collected from within an adjacent exposure of till (UVTRL 99W031, 75 annual rings).

OBSERVATIONS

The 17 subfossil stumps located in growth position in 1999 consisted of a mixed stand of 125- to 225-year-old subalpine fir (n = 5), Englemann spruce (n = 5), whitebark pine trees (n = 2) and five unidentified pine/spruce trees. The two samples of perimeter wood have contemporaneous radiocarbon ages (2,870 ± 60 and 2,830 ± 60 ^{14}C years B.P.; Table 1). The stumps were rooted in a deeply weathered pedogenic surface and, prior to their exposure, were buried by 3–5 m of sediment.

Although the sedimentological evidence is fragmentary, our interpretation is that the subfossil tree stumps were initially partially buried by ice proximal outwash sediments before being overridden and decapitated by the advancing Saskatchewan Glacier. The presence of a wood fragment with an age of 2,910 ± 60 ^{14}C years B.P. (Table 1) and laterally extensive gravel lenses in the overlying till suggests the site was subsequently buried by subglacially deposited sediments (Meier 1960). Small-scale glacial flutes on the till surface indicate there was a subsequent post-depositional deformation episode by active ice (McPherson and Gardner 1969; Boyce 1993).

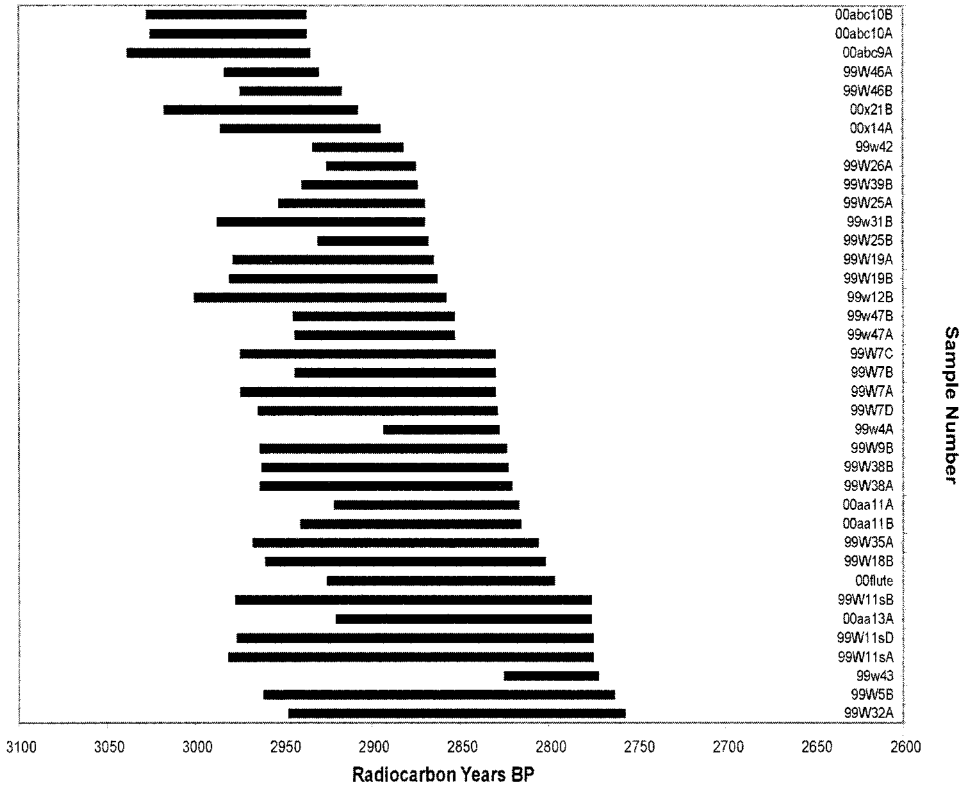

Figure 3. Summary of dendroglaciological studies of subfossil stumps and detrital wood found at the Saskatchewan Glacier. The figure illustrates the duration of the combined crossdated ring width records of subfossil subalpine fir and whitebark pine samples. Note that each record does not necessarily represent the absolute age of each tree, as many of the samples were incomplete or showed evidence of surface abrasion.

Figure 3 illustrates the duration of our combined crossdated records of subfossil subalpine fir and whitebark pine samples. Although some samples did not include the pith and many showed evidence of surface abrasion, there is an indication that the subfossil samples recovered in 1999 and 2000 were killed between *ca.* 2,940 and 2,760 ^{14}C years B.P. With one exception, these dates are comparable to those reported earlier (Table 1) and collectively reflect the consequences of a single Neoglacial advance of the Saskatchewan Glacier into an established valley bottom forest.

DISCUSSION

The *Peyto Advance* was designated by Luckman *et al.* (1993) to describe a mid-Holocene advance of Peyto Glacier in Banff National Park. Glacially-sheared stumps dated to 3,000 to 2,800 ^{14}C years B.P. at Peyto Glacier correlate to Neoglacial advances with similar ages in the Canadian Rocky Mountains at Yoho (Luckman 1993), Robson (Luckman *et al.* 1993) and Stutfield glaciers (Osborn *et al.* 2001). This glacial episode appears throughout glacial record in the southern Canadian Cordillera and is believed coeval with the Neoglacial *Tiedemann Advance* dating to between 2,940 and 2,250 ^{14}C years B.P. in the British Columbia Coast Ranges (Fulton 1971; Ryder and Thomson 1986).

In this instance, the radiocarbon-dated ring-width chronologies derived from sheared stumps and detrital wood at the Saskatchewan Glacier support previous findings of increased glacier extent *ca.* 3,000 ^{14}C years B.P. in the Canadian Rocky Mountains. Their position a considerable distance down valley from the source of the Saskatchewan Glacier in the Columbia Icefield leaves unresolved the question as to whether Neoglacial ice advances were initiated regionally by 4,000 ^{14}C years B.P. There is convincing lichenometric and dendroglaciological evidence within the Columbia Icefield area to suggest that small cirque glaciers like Hilda Glacier (Carter *et al*. 1999) and Boundary Glacier (Gardner and Jones 1985; Table 1) had responded to changing climates by this time. An examination of recently exposed rooted stumps at nearby Boundary Glacier in 2001, close to the site first described by Gardner and Jones (1985), confirms that this small cirque-bound glacier was advancing into treeline by 3,880 ^{14}C years B.P. (Table 1). We suspect that large icefield-generated valley glaciers like the Saskatchewan Glacier had slower response times and would have required hundreds of years to advance to the site documented in this paper. Nevertheless, we cannot unequivocally describe the events at Boundary and Saskatchewan glaciers as equivalent time-transgressive responses to the shift from nonglacial Hypsithermal to Neoglacial conditions in the period 5,000–3,500 ^{14}C years B.P. (Beaudoin and King 1990; Leonard and Reasoner 1999).

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