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Western Canadian glaciers advance in concert with climate change circa 4.2 ka

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[1] Disparate climate proxies from the Northern Hemisphere record a climate event at 4.2–3.8 ka. Here we show that glaciers throughout the mountain ranges of western Canada advanced at about this time. This conclusion is based on (1) new and previously reported radiocarbon ages on in situ stumps, logs, branches, and soils exposed by recent retreat in glacier forefields and (2) clastic-rich sediment intervals in cores retrieved from four montane lakes. These glacier and lacustrine data indicate a period of several decades to century length when climate conditions (cool summers, wet winters or both) favoured glacier nourishment and advance across western Canada.

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1. Introduction

[2] The geologic record reveals that mountain glaciers in the Northern Hemisphere responded to climate variations on time scales ranging from decades to millennia through the Holocene. Insolation-induced changes in summer temperature account for the progressive expansion of glaciers through the Holocene [*Davis and Osborn*, 1987; *Luckman*, 2000], but superimposed on this long-term trend are periods when glaciers advanced and retreated on time scales of decades to centuries. Glaciers in western Canada and the U.S. Pacific Northwest, for example, advanced during the 8.2 ka cold event [*Menounos et al.*, 2004; F. Anslow, unpublished data, 2007], a short-lived cool interval that is recorded in many environmental proxies in the Northern Hemisphere [*Alley and Ágústsdóttir*, 2005]. Likewise, glaciers in the Canadian Rockies advanced during the Little Ice Age (AD1200-1900) when both precipitation and temperature favored glacier growth [*Luckman*, 2000].

[3] Recent studies document a climatic event with global significance centered at 4.2–3.8 ka [*Weiss et al.*, 1993; *Viau et al.*, 2002; *Mayewski et al.*, 2004; *Booth et al.*, 2005; *Zhang and Hebda*, 2005]. In this paper, we show that glaciers in several mountain ranges in western Canada advanced between 4.4 and 4.0 ka. The critical evidence for this advance comes from tree stumps in growth position, detrital branches and logs, peat layers below till near present glacier margins, and the clastic content of proglacial lake sediments. Our results are important because they help to assess the spatial distribution and severity of climatic change during the Holocene.

2. Study Area and Methods

[4] Our sites are located in British Columbia's southern Coast Mountains, in ranges of the northern and southern British Columbia interior, and in the southern Rocky Mountains (Figure 1). Previously published radiocarbon ages come from Garibaldi Provincial Park [*Koch et al.*, 2007; *Osborn et al.*, 2007] and the Monashee Mountains [*Ryder and Thomson*, 1986]. We obtained additional radiocarbon ages on detrital wood and in situ stumps from glacier forefields and lateral moraines in other ranges. Detrital wood was collected and only dated where delivery by snow avalanches or from trees growing on valley sides above the glacier could be ruled out. We recognize, however, that this sampling strategy cannot completely preclude the possibility that wood reached the glacier by mass wasting if treeline was higher in the past.

[5] We limit our analysis to detrital and in situ wood dated to between 4.50 and 3.50 ^{14}C ka. Some of the ages reported here are new, whereas others have been previously published [*Gardner and Jones*, 1985; *Ryder and Thomson*, 1986; *Koch et al.*, 2007; *Osborn et al.*, 2007]. A radiocarbon age of 4.36 ± 0.08 ^{14}C ka from Gilbert Glacier is excluded from further consideration because it does not relate to activity of the glacier [*Ryder and Thomson*, 1986].

[6] Radiocarbon ages from glacier forefields are supplemented with data gathered from proglacial Green, Lower Joffre, Diamond, and Red Barrel lakes (Figure 1), sites that we have studied in detail in the past [*Filippelli et al.*, 2006; *Lakeman et al.*, 2008]. Glaciers today cover, respectively, 7%, 25%, 0%, and 5% of these four lakes' watersheds. At the peak of the Little Ice Age, glacier cover in the four watersheds was 12%, 30%, 16%, and 14% [*Filippelli et al.*, 2006; *Osborn et al.*, 2007; *Lakeman et al.*, 2008]. Sediment cores retrieved from the four lakes were analyzed for particle size, magnetic susceptibility, density, and water and organic matter content. However, only water and organic matter content were analyzed at sufficiently high resolution to contribute meaningful data to our study. We measured the organic content of sediments in the cores at a 1-cm interval by the loss-on-ignition (LOI) method [*Dean*,

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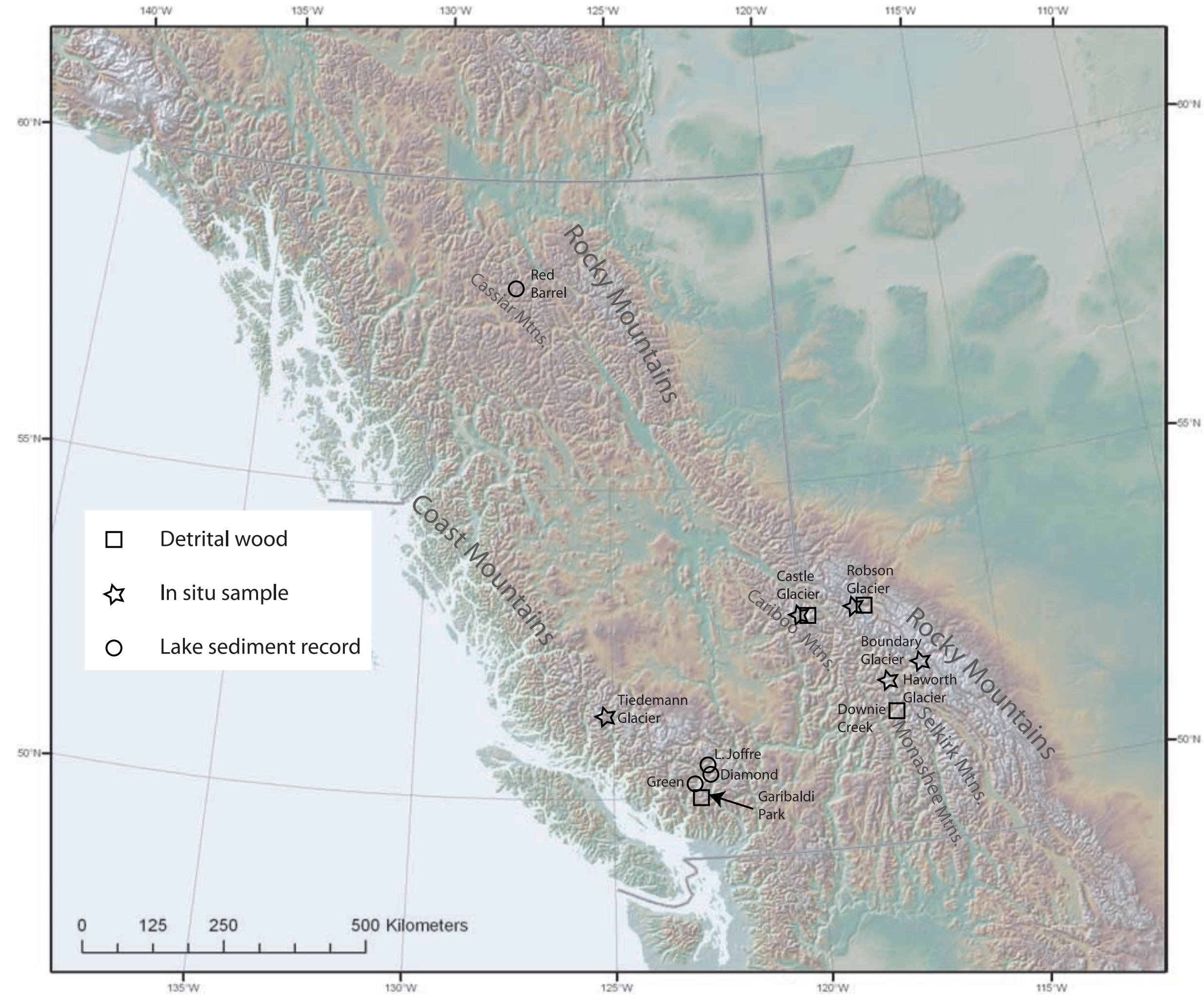

Figure 1. Locations of sites with evidence for glacier fluctuations reported in this paper.

1974]. Variations in LOI commonly reflect changes in glacigenic sediment supply to the lake [e.g., *Karlén*, 1981].

[7] Plant fossils collected from glacier forefields and lake sediment cores were radiocarbon dated by standard (radiometric) and AMS methods. Radiocarbon ages were converted to calendric ages with the calibration program CALIB 5.02 (M. Stuiver et al., 2005, available at http://calib.qub.ac.uk/calib/). Age-depth models for lake sediment cores were constructed by linearly interpolating between calibrated radiocarbon ages obtained from conifer needles and other plant macrofossils. Mazama, Bridge River, and White River tephras, which are, respectively, about 7.70, 2.40, and 1.15 ka [*Clague et al.*, 1995; *Hallett et al.*, 1997], provided additional age control for some cores.

3. Results

3.1. Glacier Forefield Evidence

[8] Stumps in growth position and detrital wood collected from glacier forefields in the Coast Mountains indicate glaciers expanded between 4.40 and 4.00 ka (Figure 1 and Table 1). In Garibaldi Park, wood near the snout of Helm Glacier yielded a radiocarbon age of 4.08 ± 0.04 ^{14}C ka [*Koch et al.*, 2007]. Detrital wood in till at nearby Sphinx Glacier produced radiocarbon ages of 4.28 ± 0.07 and 3.56 ± 0.07 ^{14}C ka, and two samples of detrital wood in the forefield of Spearhead Glacier, also in Garibaldi Park, gave ages of 3.90 ± 0.06 and 3.90 ± 0.08 ^{14}C ka [*Osborn et al.*, 2007]. The stem of a glacially overridden tree in the forefield of Goddard Glacier in the Coast Mountains, 150 km north-northwest of Spearhead Glacier, yielded an age of 4.12 ± 0.06 ^{14}C ka. Stumps in growth position occur at several levels in the north lateral moraine of Tiedemann Glacier, about 200 km north-northwest of Garibaldi Park (Figure 1). *Ryder and Thomson* [1986] initially described the moraine stratigraphy, but glacier downwasting since their study has exposed additional, older sediments. Stumps rooted in soils in outwash sand and silt at two sites returned radiocarbon ages of 3.86 ± 0.02, 3.82 ± 0.02, 3.75 ± 0.06, and 3.72 ± 0.050 ^{14}C ka (Table 1). The outwash is overlain and underlain by tills.

[9] New and published radiocarbon ages from glacier forefields in the Cariboo, Monashee, Selkirk, and Rocky mountains provide additional evidence for a glacier advance at about 4.2 ka (Figure 1 and Table 1). Stumps in growth position and detrital wood with preserved bark at Castle Glacier in the Cariboo Mountains yielded five radiocarbon ages between 4.21 ± 0.08 and 3.69 ± 0.02 ^{14}C ka (Table 1).

Table 1. Radiocarbon Ages Reported in This Study

Lab[a]	Glacier	Context	Radiocarbon Age, ^{14}C ka	Calibrated Age,[b] ka	Reference
		Southern Coast Mountains (Garibaldi Provincial Park)			
Beta-208685	Sphinx	Log in till, 500 m from snout	4.28 ± 0.07	5.04 – 4.59	*Koch et al.* [2007]
Beta-186523	Helm	Detrital stump at glacier snout	4.08 ± 0.04	4.81 – 4.44	*Koch et al.* [2007]
Beta-168423	Spearhead	Detrital wood in forefield	3.90 ± 0.06	4.51 – 4.15	*Osborn et al.* [2007]
Beta-157268	Spearhead	Detrital wood in forefield	3.90 ± 0.08	4.53 – 4.09	*Osborn et al.* [2007]
Beta-186570	Sphinx	Detrital wood in till	3.56 ± 0.07	4.08 – 3.64	*Koch et al.* [2007]
		Southern Coast Mountains (Ty'ylos, Homathko River - Tatlayoko Park)			
GSC-6046	Goddard	Detrital wood in forefield	4.12 ± 0.06[c]	4.82 – 4.53	This study
UCIAMS-40663	Tiedemann	Rooted stump in lateral moraine	3.86 ± 0.02	4.41 – 4.18	This study
UCIAMS-40660	Tiedemann	Rooted stump in lateral moraine	3.82 ± 0.02	4.29 – 4.10	This study
Beta-220940	Tiedemann	Rooted stump in lateral moraine	3.75 ± 0.06	4.35 – 3.92	This study
Beta-220936	Tiedemann	Rooted stump in lateral moraine	3.72 ± 0.05	4.23 – 3.91	This study
		Interior Ranges			
GSC-169	Downie[d]	Detrital log in till	3.76 ± 0.07	4.24 – 3.99	*Ryder and Thomson* [1986]
GSC-6772	Haworth	Rooted stump in forefield	3.87 ± 0.06	4.41 – 4.16	This study
GSC-6709	Castle[e]	Rooted stump in forefield	4.21 ± 0.08	4.84 – 4.65[f]	This study
UCIAMS-40543	Castle	Rooted stump in forefield	3.72 ± 0.02	4.15 – 3.99	This study
GSC-6700	Castle	Detrital log in forefield	3.71 ± 0.08	4.22 – 3.93	This study
UCIAMS-40544	Castle	Detrital wood in forefield	3.69 ± 0.02	4.09 – 3.93	This study
		Rocky Mountains			
WAT-1182	Boundary	Rooted stump in forefield	4.05 ± 0.04	4.82 – 4.53	*Gardner and Jones* [1985]
WAT-1183	Boundary	Peat below till in forefield	3.88 ± 0.06	4.51 – 4.10	*Gardner and Jones* [1985]
Beta-160362	Boundary	Rooted stump in forefield	3.88 ± 0.04	4.42 – 4.16	*Wood and Smith* [2004]
Beta-65381	Robson	Root in paleosol	3.71 ± 0.07	4.29 – 3.85	*Luckman* [1995]
Beta-65382	Robson	Rooted stump in forefield	3.65 ± 0.06	4.25 – 3.83	*Luckman* [1995]

[a] Radiocarbon laboratory: Beta, Beta Analytic Inc; GSC, Geological Survey of Canada; UCIAMS, University of California; and Wat, University of Waterloo.

[b] Calendar ages (±2σ) determined using CALIB 5.02 (M. Stuiver et al., 2005, available at http://calib.qub.ac.uk/calib/).

[c] Analytical uncertainty is 2σ for all GSC ages.

[d] Unnamed glacier in headwaters of Downie Creek (51.30°N, 118.02°W) reported by *Ryder and Thomson* [1986].

[e] Unofficial name (53.05°N, 120.44°W).

[f] Calibrated age range has been adjusted to account for the number of rings between the pith and the cambium.

A rooted stump near the snout of Haworth Glacier in the Selkirk Mountains gave an age of 3.87 ± 0.06 ^{14}C ka, while a log in till from the headwaters of Downie Creek provided an age of 3.76 ± 0.07 ^{14}C ka (Table 1 and Figure 1). Two rooted stumps in the forefield of Boundary Glacier in the Canadian Rockies yielded ages of 4.05 ± 0.07 and 3.88 ± 0.04 ^{14}C ka, and peat below till at the same site gave an age of 3.88 ± 0.06 ^{14}C ka [*Gardner and Jones*, 1985; *Wood and Smith*, 2004]. A stump and in situ root collected near the terminus of Robson Glacier in the Canadian Rockies in 1993 returned ages of, respectively, 3.71 ± 0.07 and 3.65 ± 0.06 ^{14}C ka [*Luckman*, 1995].

[10] The 21 radiocarbon ages mentioned above cluster in two groups (Table 1). Sixteen samples have a calibrated age range of 4.53–3.83 ka; eight of these 16 samples are outer rings of in situ stumps, and one is a root. Five samples have a calibrated age range of 5.04–4.44 ka; they too are derived from both detrital and in situ material. The age range of the prominent peak in the age distribution from in situ material is 4.40–4.00 ka (Figure 2).

3.2. Evidence from Lakes

[11] The clastic content of sediment cores from Green, upper Joffre, Diamond, and Red Barrel lakes increases from early Holocene time to the present (Figure 2). Superimposed on this long-term trend are clastic-rich units, commonly spanning centuries, that are apparent in the LOI trends in the cores (Figure 2). The clastic-rich units are denser, contain less water and less organic matter, and have higher magnetic susceptibilities than surrounding sediments. A notable clastic unit, centered between 4.4–4.0 ka, appears in all four sediment records (Figure 2). For each core, we use the interval that is bounded on both sides by half of the minimum organic matter values in that core as a measure of the age range of the unit: 4.13–4.03 ka in Green Lake; 4.35–4.07 ka in lower Joffre Lake; 4.3–3.8 ka in Diamond Lake; and 4.32–4.10 ka in Red Barrel Lake. Given the typical errors in terrestrial macrofossil radiocarbon ages (40–60 a) and the likelihood of non-linear sedimentation rates, the true age range of the clastic unit could differ from the above-cited values by 0.15–0.30 ka.

4. Discussion

[12] Radiocarbon ages on in situ stumps in glacier forefields reported in this study delimit a period of glacier advance. We infer that glaciers advanced into forests, remnants of which are preserved stumps. Our interpretation that the advance was regional is supported by the wide distribution, number, and similar ages of in situ plant fossils. Radiocarbon ages of in situ material indicate that glaciers overrode forests as early as 4.9 ka, but the prominent peak in the age distribution of in situ material is ca. 4.3 ka (Figure 2).

[13] Stumps and detrital wood can be used to pinpoint approximate times when glaciers advanced, but they can not resolve whether glaciers expanded slowly over periods of

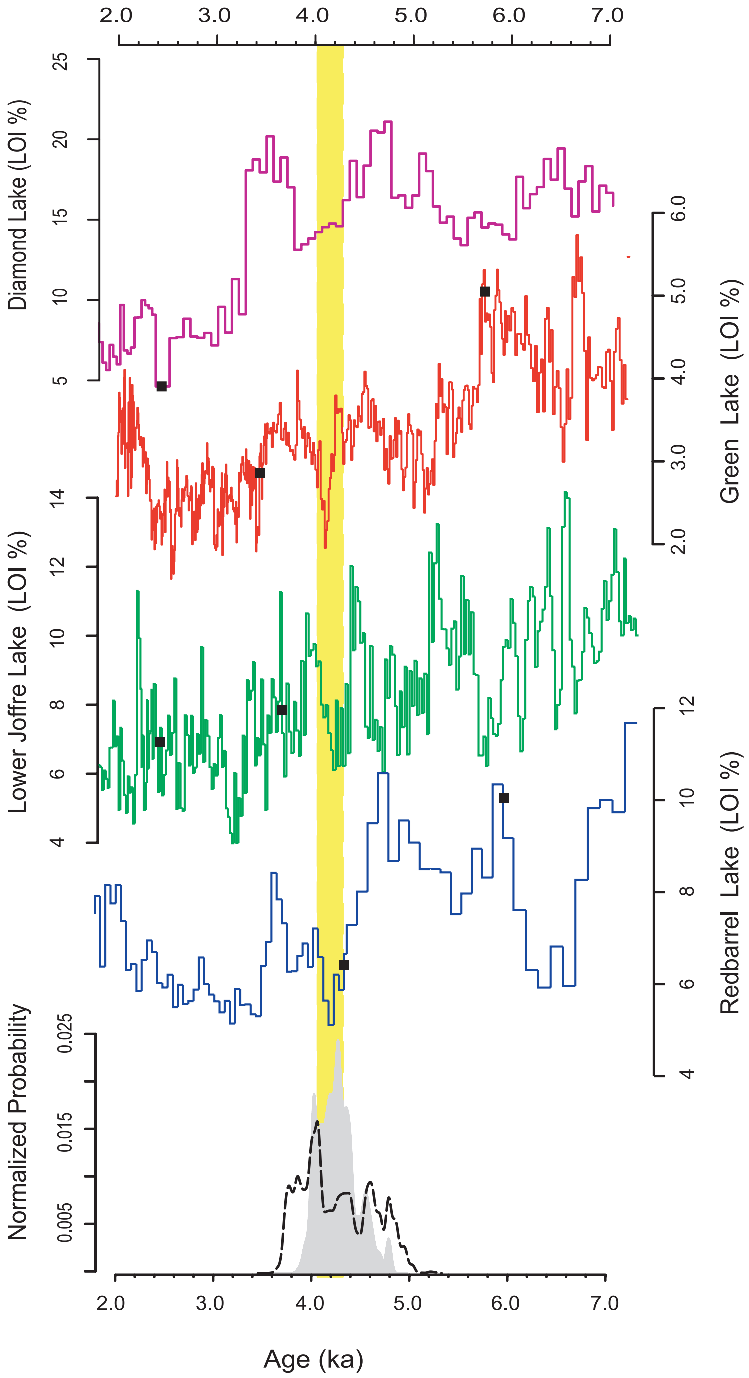

Figure 2. Comparison of clastic events inferred from lake sediment cores and radiocarbon ages of wood samples collected from glacier forefields. The upper four graphs plot loss-on-ignition, an index for the clastic content of lake sediments, for cores from Green, lower Joffre, Diamond, and Red Barrel lakes (Figure 1). The early and late Holocene parts of these records have been omitted to emphasize clastic events between 5.16 and 3.76 ka. Control points for the linear age-depth models include AMS ^{14}C ages of terrestrial macrofossils and tephras (black squares). Age resolution for ca. 4.0 ka-old sediment from Green, lower Joffre, Diamond, and Red Barrel lakes is 10, 23, 70, and 50 a, respectively. Additional dating control for Red Barrel and Diamond lakes and for Green and lower Joffre lakes is provided by White River and Mazama tephras (age control points not shown), respectively,. The lower graph is the smoothed (100 a) age distribution for detrital (dashed) and in situ (filled) material in glacier forefields. The vertical yellow bar indicates the age range where the clastic intervals and the age maxima overlap.

hundreds of years or advanced more than once, on shorter timescales, with intervening recession. Faced with this problem, *Ryder and Thomson* [1986] coined the term 'Garibaldi phase' to denote glacier activity in Garibaldi Provincial Park between 6.0 and 5.0 ^{14}C ka. The same issue applies to our dataset. Radiocarbon ages on stumps in growth position at Castle Glacier indicate that the glacier was advancing downvalley between 4.9 and 4.2 ka, but the dating control is insufficient to indicate whether this was a single or several closely spaced advances. Integration of terrestrial and lacustrine data sheds some light on this question. The lake sediment records clearly indicate a local maximum in clastic sediment delivery to the lakes at about 4.2 ka. The records also indicate that clastic sedimentation was low before and after the peak at 4.2 ka.

[14] Together with the dated in situ stumps, the clastic sediment records support the evidence for a regional advance of alpine glaciers ca. 4.2 ka. Given uncertainties in radiocarbon ages, we assign an age range to this advance of 4.4–4.0 ka. We informally denote this event 'the 4.2 ka advance'. Glaciers advanced as early as 4.9 ka in western Canada, but factors responsible for early expansion are unknown. However, the age range ascribed to the climate event at 4.2–3.8 ka and the peak in the age distribution of stumps that were overrun by glaciers are in accord (Figure 2). We therefore implicate the 4.2–3.8 ka climate change event as the trigger for the glacier advance at 4.2 ka.

[15] Based on the location of the overridden material, the 4.2 ka advance was smaller than some subsequent, middle and late Neoglacial advances. For example, it was not as extensive as the middle Neoglacial Tiedemann advance [*Ryder and Thomson*, 1986], nor the Little Ice Age glacier advances of the 17th, 18th, and 19th centuries. At Tiedemann Glacier, the rooted stumps exposed in the north lateral moraine are below till with bracketing ages of 3.6–2.4 ka [*Ryder and Thomson*, 1986]. Also, the lake sediments attributed to the 4.2 ka advance contain less mineral matter than younger sediments.

[16] Regional climatic conditions that allowed glaciers to advance at 4.2 ka are unknown, although it is likely that summer temperatures were cooler than average or winter precipitation was higher than average for several decades and perhaps centuries. A floating tree-ring chronology derived from fossil wood at Healy Lake, British Columbia, reveals a period of greatly reduced growth at about 3.9 ka, which broadly coincides with the transition from warm, moist conditions to cool, wet climate of the late Holocene [*Zhang and Hebda*, 2005]. *Chang and Patterson* [2005] report an increase in precipitation at about 4.4 ka based on the physical characteristics of sediments recovered from Effingham Inlet on Vancouver Island. Wet conditions are also inferred from cave sediments in Texas at 4.4 ka [*Ellwood and Gose*, 2006]. *Viau et al.* [2002] document a major climatic shift at 4.0 ka based on analysis of radiocarbon-dated pollen assemblages throughout North America. In contrast, a number of proxy data indicate that a severe drought struck the mid continent of North America between 4.3 and 4.1 ka, and this drought may have been caused by a prolonged interval of cool sea surface temperatures (La Niña) in the Equatorial eastern Pacific [*Booth et al.*, 2005]. Our data support this hypothesis since, in contrast to the central Plains of North America, cool, wet conditions are common in northwest North America during La Niña-like events. Glacier mass balance records and proxy reconstructions confirm the association between glacier nourishment and cool sea surface temperatures in the Equatorial eastern Pacific [*Bitz and Battisti*, 1999; *Watson et al.*, 2006].

5. Implications and Conclusions

[17] To our knowledge, our study is the first to report a regional advance of alpine glaciers in western North America at 4.2 ka. Earlier studies reported glacier activity at this time, but the number of sites and amount of direct evidence for an advance, such as stumps in growth position, were limited. In addition, our lake sediment data indicate an episode of clastic sedimentation at this time that is characteristic of short-lived glacier advances and not slow, progressive expansion of glaciers during the Neoglacial.

[18] Global evidence for an advance of alpine glaciers at 4.2 ka is equivocal. *Joerin et al.* [2006] infer that six glacier in the Swiss Alps were restricted in extent between 4.3 and 3.4 ka, although they identify a possible minor advance at 4.4–4.3 ka. *O'Brien et al.* [1995] and *Mayewski et al.* [2004] report glacier advances in North America during the period 4.2–3.8 ka based on data presented by *Denton and Karlén* [1973]. However, *Denton and Karlén* [1973] identify the period 4.0–3.3 ka as one of glacier recession and present no evidence to support a glacier advance between 4.9 and 4.0 ka. The only radiocarbon age reported in their paper that may relate to glacier expansion during the 4.2 ka advance is from a spruce log in alluvium in front of Giffin Glacier, Alaska (3.58 ± 0.10 ^{14}C ka; I-6414).

[19] Regional evidence shows that glaciers in western Canada advanced about 8.1, 6.7, 2.3, 1.7, and 0.8 ka [*Ryder and Thomson*, 1986; *Menounos et al.*, 2004; *Koch et al.*, 2007; *Osborn et al.*, 2007]. Our study indicates that glaciers also advanced at about 4.2 ka, during a period when no regional advances were documented. The cause of the 4.2 ka climate event remains uncertain, but the event was sufficient to generate glacier expansion across western Canada at that time.

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References

Alley, R., and A. M. Ágústsdóttir (2005), The 8k event: Cause and consequences of a major Holocene abrupt climate change, *Quat. Sci. Rev.*, *24*, 1123–1149.

Bitz, C. M., and D. S. Battisti (1999), Interannual to decadal variability in climate and the glacier mass balance in Washington, western Canada, and Alaska, *J. Clim.*, *12*, 3181–3196.

Booth, R., S. Jackson, S. Forman, K. Kutzbach, E. Bettis, J. Kreigs, and D. Wright (2005), A severe continental-scale drought in mid-continental North America 4200 years ago and apparent global linkages, *Holocene*, *15*, 321–328.

Chang, A. S., and R. T. Patterson (2005), Climate shift at 4400 years: Evidence from high-resolution diatom stratigraphy, Effingham Inlet, British Columbia, Canada, *Palaeogeogr. Palaeoclimatol. Palaeoecol.*, *226*, 72–92.

Clague, J. J., S. G. Evans, V. N. Rampton, and G. J. Woodsworth (1995), Improved age estimates for the White River and Bridge River tephras, western Canada, *Can. J. Earth Sci.*, *32*, 1172–1179.

Davis, T. P., and G. Osborn (1987), Age of pre-Neoglacial cirque moraines in the central North American Cordillera, *Geogr. Phys. Quat.*, *41*, 365–375.

Dean, W. (1974), Determination of carbonate and organic matter in calcareous sediments and sedimentary rocks by loss on ignition: Comparison with other methods, *J. Sediment. Petrol.*, *44*, 242–248.

Denton, G. E., and W. Karlén (1973), Holocene climatic variations: Their pattern and possible causes, *Quat. Res.*, *3*, 155–205.

Ellwood, B. B., and W. A. Gose (2006), Heinrich H1 and 8200 yr B. P. climatic events recorded in Hall's Cave, Texas, *Geology*, *34*, 753–756.

Filippelli, G., C. Souch, B. Menounos, S. Slater-Atwater, and O. Slaymaker (2006), Alpine lake sediment records of the impact of glaciation and climate change on the biogeochemical cycling of soil nutrients, *Quat. Res.*, *66*, 158–166.

Gardner, J. S., and N. K. Jones (1985), Evidence for a Neoglacial advance of the Boundary Glacier, Banff National Park, Alberta, *Can. J. Earth Sci.*, *22*, 1753–1755.

Hallett, D. J., L. V. Hills, and J. J. Clague (1997), New accelerator mass spectrometry radiocarbon ages for the Mazama tephra layer from Kootenay National Park, British Columbia, *Can. J. Earth Sci.*, *34*, 1202–1209.

Joerin, U. E., T. F. Stocker, and C. Schlüchter (2006), Multicentury glacier fluctuations in the Swiss Alps during the Holocene, *Holocene*, *16, 697–704.*

Karlén, W. (1981), Lacustrine sediment studies: A technique to obtain a continuous record of Holocene glacier variations, *Geogr. Ann., Ser. A*, *63*, 273–281.

Koch, J., G. D. Osborn, and J. J. Clague (2007), Pre-'Little Ice Age' glacier fluctuations in Garibaldi Provincial Park, Coast Mountains, British Columbia, Canada, *Holocene*, *17*, 1069–1078.

Lakeman, T., J. J. Clague, and B. Menounos (2008), Advance of alpine glaciers during final retreat of the Cordilleran ice sheet in the Finlay River area, northern British Columbia, Canada, *Quat. Res.,* in press.

Luckman, B. H. (1995), Calendar-dated, early 'Little Ice Age' glacier advance at Robson Glacier, British Columbia, Canada, *Holocene*, *5*, 149–159.

Luckman, B. H. (2000), The Little Ice Age in the Canadian Rockies, *Geomorphology*, *32*, 357–384.

Mayewski, P. A., et al. (2004), Holocene climate variability, *Quat. Res.*, *62*, 243–255.

Menounos, B., J. Koch, G. Osborn, and J. J. Clague (2004), Early Holocene glacier advance, southern Coast Mountains, British Columbia, *Quat. Sci. Rev.*, *23*, 1543–1550.

O'Brien, S. R., P. A. Mayewski, L. D. Meeker, M. S. Twickler, and S. I. Whitlow (1995), Complexity of Holocene climate as reconstructed from a Greenland ice core, *Science*, *270*, 1962–1964.

Osborn, J., B. Menounos, J. J. Clague, J. Koch, and V. Vallis (2007), Multi-proxy record of Holocene glacial history of the Spearhead and Fitzsimmons ranges, southern Coast Mountains, *Quat. Sci. Rev.*, *26*, 479–493.

Ryder, J. M., and B. Thomson (1986), Neoglaciation in the southern Coast Mountains of British Columbia: Chronology prior to the late Neoglacial maximum, *Can. J. Earth Sci.*, *23*, 273–287.

Viau, A., K. Gajewski, P. Fines, D. Atkinson, and M. Sawada (2002), Widespread evidence of 1500 yr climate variability in North America during the past 14000 yr, *Geology*, *30*, 455–458.

Watson, E., B. H. Luckman, and B. Yu (2006), Long-term relationships between reconstructed seasonal mass balance at Peyto Glacier, Canada and Pacific variability, *Holocene*, *16*, 783–790.

Weiss, H., M. A. Courty, W. Wetterstrom, F. Guichard, L. Senior, R. Meadow, and A. Curnow (1993), The genesis and collapse of third millennium north Mesopotamian civilization, *Science*, *261*, 995–1004.

Wood, C., and D. J. Smith (2004), Dendroglaciological evidence for a Neoglacial advance of the Saskatchewan Glacier, Banff National Park, Canadian Rocky Mountains, *Tree Ring Res.*, *60*, 59–65.

Zhang, Q., and R. Hebda (2005), Abrupt climate change and variability in the past four millennia of the southern Vancouver Island, *Geophys. Res. Lett.*, *32*, L16708, doi:10.1029/2005GL022913.

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