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Mid-Holocene Glacier Peak and Mount St. Helens We Tephra Layers Detected in Lake Sediments from Southern British Columbia Using High-Resolution Techniques

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A Glacier Peak tephra has been found in the mid-Holocene sediment records of two subalpine lakes, Frozen Lake in the southern Coast Mountains and Mount Barr Cirque Lake in the North Cascade Mountains of British Columbia, Canada. The age–depth relationship for each lake suggests an age of 5000–5080 ^{14}C yr B.P. (5500–5900 cal yr B.P.) for the eruption which closely approximates the estimated age (5100–5500 ^{14}C yr B.P.) of the Dusty Creek tephra assemblage found near Glacier Peak. The tephra layer, which has not been reported previously from distal sites and was not readily visible in the sediments, was located using contiguous sampling, magnetic susceptibility measurements, wet sieving, and light microscopy. The composition of the glass in pumice fragments was determined by electron microprobe analysis and used to confirm the probable source of this mid-Holocene tephra layer. Using the same methods, the A.D. 1481–1482 Mount St. Helens We tephra layer was identified in sediments from Dog Lake in southeastern British Columbia, suggesting the plume drifted further north than previously thought. This high-resolution method for identifying tephra layers in lake sediments, which has worldwide application in tephrachronologic/paleoenvironmental studies, has furthered our knowledge of the timing and airfall distribution of Holocene tephras from two important Cascade volcanoes.

INTRODUCTION

Tephra produced by volcanic eruptions is transported hundreds and sometimes thousands of kilometers downwind where it accumulates in lakes, bogs, alluvium, colluvium, soils, dunes, and marine sediments (Sarna-Wojcicki *et al.*, 1983). Primary airfall tephra deposits are common in lake sediment records of western North America and represent important late Quaternary stratigraphic markers (Foit *et al.*, 1993; Hallett *et al.*, 1997; Leonard, 1996; Mehringer *et al.*, 1977, 1984; Reasoner and Healy, 1986; Whitlock *et al.*, 2000). These tephras provide chronological control for archaeologists, geologists, paleoecologists, physical geographers, and volcanologists in a variety of depositional sequences in western North America (Sarna-Wojcicki *et al.*, 1983, 1991).

In the Pacific Northwest of the United States and western Canada, the most common and widespread late Quaternary tephra layers erupted from Mount Mazama (Crater Lake, Oregon) during the mid-Holocene (Bacon, 1983; Sarna-Wojcicki *et al.*, 1991). Several widespread tephra layers that are closely spaced in time have erupted from Glacier Peak (Beget, 1982, 1984, 1985; Porter, 1978; Westgate and Evans, 1978) and from Mount St Helens (Crandell, 1987; Mullineaux, 1986, 1996) in the Cascade Range. The Bridge River tephra, from Mount Meager, is also an important late Holocene marker across southern British Columbia (Clague *et al.*, 1995; Leonard, 1996; Mathewes and Westgate, 1980). While these well-documented tephra layers are often obvious in lake sediment records, less visibly obvious tephra layers produced by minor Cascade eruptions often go unnoticed.

Evidence of long-distance tropospheric transport of tephra and stratospheric transport of sulfate aerosol from the Cascade Range has appeared in the GISP2 ice cores from Greenland (Fiacco *et al.*, 1993; Mayewski *et al.*, 1986; Ram and Gayley, 1991; Zdanowicz *et al.*, 1999; Zielinski *et al.*, 1994). The sparseness and extremely small particle size of distal tephra requires the use of high-resolution sampling and techniques that include

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geochemical identification of sulfate peaks, microparticle concentration analysis to locate tephra layers in the ice cores, and microprobe analysis to identify the source of the eruption. The calendrical ages of the distal Cascade tephra layers, such as those from Mazama, have been verified recently using the GISP2 ice core chronology (Zdanowicz *et al.*, 1999) and have been compared to local radiocarbon age estimates of the climactic eruption (Bacon, 1983; Hallett *et al.*, 1997). Similarily, the GISP2 based calendrical age of Mount St. Helens Wn tephra dates the eruption at A.D. 1479–1480 (Fiacco *et al.*, 1993), further refining local age estimates of this tephra deposit (Smith *et al.*, 1977; Yamaguchi, 1983, 1985). This hemispheric analysis of tephra layers allows researchers to compare various paleoenvironmental records using similar chronologies.

Fine or invisible tephra deposits have been discovered in lake sediments and peat deposits across northern Europe and Alaska using magnetic susceptibility, high-resolution sampling, light microscopy, and electron microprobe analysis. Tephrachronologies from volcanoes, such as Hekla in Iceland (Dugmore *et al.*, 1992, 1996; Eiriksson *et al.*, 2000; Haflidason *et al.*, 2000; Pilcher *et al.*, 1996; Turney *et al.*, 1997) and Redoubt, Katmai, Mount St. Augustine, and Crater peak at Mt. Spurr in Alaska (Beget *et al.*, 1994; Stihler *et al.*, 1992), have been refined in the past decade and now very thin or invisible tephra deposits can be used to correlate and date sedimentary deposits. In this paper, we describe a combination of high-resolution methods for examining lake cores and their use in identifying discrete volcanic tephra layers that are not readily visible. We present two new tephra layers that have not been previously reported from sites in British Columbia, Canada. We encourage the use of magnetic susceptibility, high-resolution sediment sampling, light microscopy, and electron microprobe analysis to better define the timing and extent of eruptions in western North America.

SAMPLING AND ANALYTICAL METHODS

Sampling Locations

High-resolution methods were used on continuous lake cores collected from three lakes, Frozen Lake (FL), Mount Barr Cirque Lake (MBC), and Dog Lake (DL), in southern British Columbia (Fig. 1). Frozen Lake (49° 36′ N latitude, 121° 28′ W longitude, elevation 1180 m, 3 ha) is located in the Coast Mountains 2 km northwest of Yale, and Mount Barr Cirque Lake (49° 16′ N latitude, 121°31′ W longitude, elevation 1376 m, 2 ha) is located in the north Cascade Mountains 10 km south of Hope. These lakes reside in the subalpine Mountain Hemlock forest zone of the Fraser Valley (Meidinger and Pojar, 1991) and are approximately 37 km apart. Dog Lake (50° 46′ N latitude, 116° 06′ W longitude, elevation 1183 m, 15.1 ha) is located 10 km south of where the Kootenay River crosses Hwy 93 in Kootenay National Park and resides in the Montane Spruce forest zone (Meidinger and Pojar, 1991).

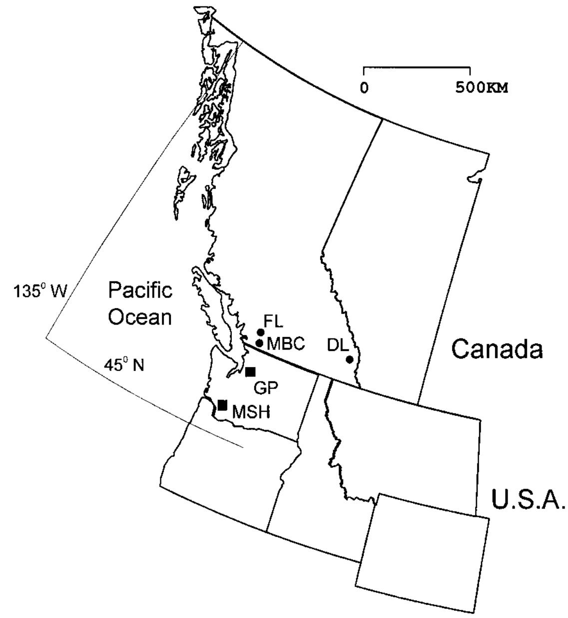

FIG. 1. Map of western North America showing the location of Mount St. Helens (MSH) and Glacier Peak (GP) volcanoes in Washington. Lake coring locations in British Columbia are Frozen Lake (FL) located 2 km northwest of Yale, Mount Barr Cirque Lake (MBC) located 10 km south of Hope, and Dog Lake (DL) located in Kootenay National Park.

Coring

In 1997, a continuous 300-cm core was extracted from the deepest part (water depth 17 m) of Frozen Lake using a percussion corer (Reasoner, 1993); the following year, a similar 290-cm core was obtained from Mount Barr Cirque Lake (depth 9 m). These cores were logged and contiguous 10-cm^3 samples of gyttja in 1.0-cm increments were obtained for their entire length. In 1998, a 60-cm surface core was extracted from Dog Lake (depth 4 m) using a 7.5-cm diameter clear lexan tube fitted with a one-way valve and operated with a rigid drive rod. The coring procedure recovered the mud–water interface intact. This core was also sampled contiguously, except that the 10-cm^3 volumes of calcareous gyttja were obtained in 0.5-cm increments using a high-resolution sampling device (Glew, 1988). All sediment samples were stored at 4°C in plastic vials.

Magnetic Susceptibility Measurements

Volumetric magnetic susceptibility (k) readings were taken on 10-cm^3 subsamples collected at contiguous 1.0-cm (FL and MBC) and 0.5-cm (DL) intervals using a coil-cup sampling device attached to a Sapphire SI-2 meter at the University of Oregon. Electromagnetic units per cubic centimeter (emu/cm^3) of sediment are presented in this paper (Figs. 2a, 2b, and 3). Magnetic susceptibility is commonly used to detect allogenic minerals in lake sediment (Thompson and Oldfield, 1986) and also can be used to detect airfall tephra layers from distant volcanoes (Beget *et al.*, 1994; Oldfield *et al.*, 1980; Stihler *et al.*, 1992). The presence of iron oxides and ferromagnesian minerals in tephras results in increased magnetic susceptibility and some peaks in

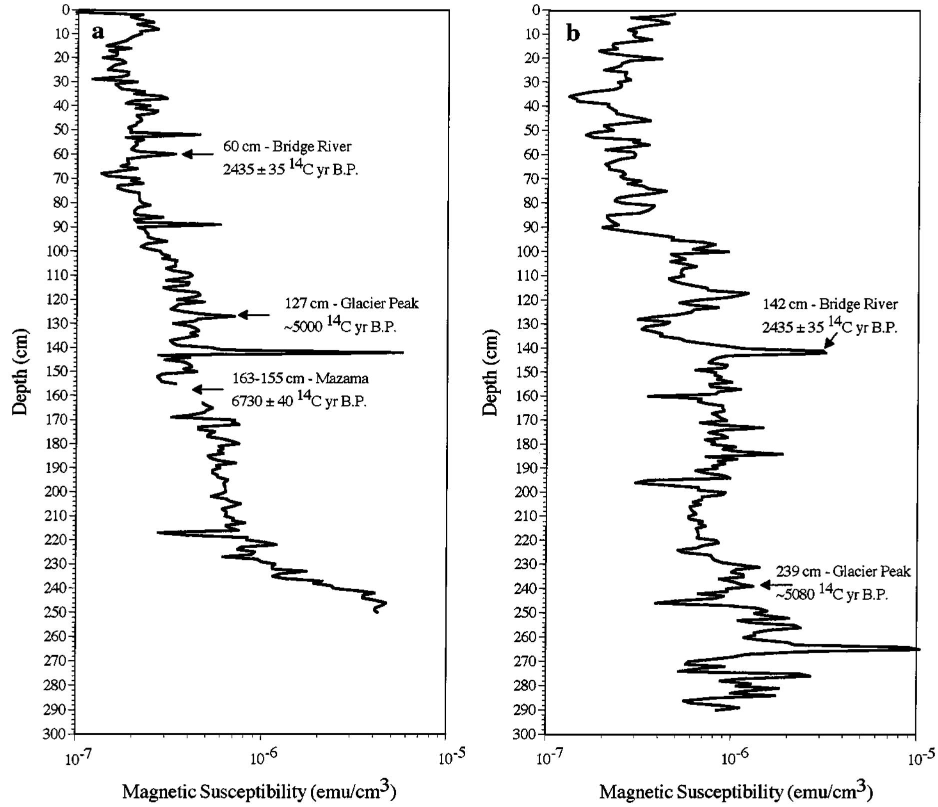

FIG. 2. (a) Frozen Lake and (b) Mount Barr Cirque Lake magnetic susceptibility versus depth data with peaks corresponding to known volcanic tephra layers. No data were collected for the Mazama tephra in the Frozen Lake core; however, the Bridge River tephra peaks are indicated by arrows at their respective depths in each core. The magnetic susceptibility peaks associated with mid-Holocene Glacier Peak tephra are indicated by arrows in both lake records.

the magnetic susceptibility record may indicate the presence of airfall tephra.

Electron Microprobe Analysis

Sediment samples of gyttja from FL and MBC were soaked for 24 hours in 10% sodium hexametaphosphate to deflocculate organic matter. The calcareous gyttja sediment from DL was soaked in 10% HCl for 24 hours to remove carbonates. The treated sediment samples were gently washed through a 125-μm sieve and residues were placed in a petri dish. Each sample residue was tallied for macroscopic charcoal and inspected at 400X magnification for volcanic glass using a dissecting microscope. If glass was present in the sample, it was isolated from the residue, dispersed in epoxy on a glass slide, polished, and then carbon coated. Some pumice fragments were set aside for scanning electron microscope imaging.

The composition of the glass in the tephra layers was determined using the Cameca electron microprobe in the GeoAnalytical Laboratory located in the Department of Geology, Washington State University. The experimental details are the same as those given in Foit *et al.* (1993) except that standard VG-A99 was used for the Fe calibration. The results are presented in Tables 1 and 2 and the compositions of the unknown glasses are compared to those of known standards using the similarity coefficient of Borchardt *et al.* (1972) as a discriminator (Table 3). Similarity coefficients were calculated using unit weighting (1.0) of the oxide concentrations of Si, Al, Ca, Fe, Na, and K and quarter weighting (0.25) of the oxide concentrations of Mg and Ti. These were given lower weighting because of their low concentrations and, consequently, high relative error of measurement.

RESULTS

Frozen and Mount Barr Cirque Lakes

All cores contained tephra layers although some were not readily observable upon routine examination. The accelerator mass spectrometry (AMS) radiocarbon-based age–depth chronology indicated that two visible tephra layers in the FL core at 162–155 cm and 60 cm (Fig. 2a) were the Mazama (Hallett *et al.*, 1997; Zdanowicz *et al.*, 1999) and Bridge River tephras, respectively (Clague *et al.*, 1995; Leonard, 1996). The AMS radiocarbon-based age–depth chronology for MBC revealed a post-Mazama record where only the Bridge River tephra layer was visible. Distinct peaks in volumetric magnetic susceptibility were observed at 60 cm (FL) and 142 cm (MBC) where the visible Bridge River tephra layer was located (Figs. 2a and 2b). The magnetic susceptibility across the 8-cm-wide Mazama tephra layer in the FL core was not measured, resulting in a gap in the record in Figure 2a. Most of the other large peaks in

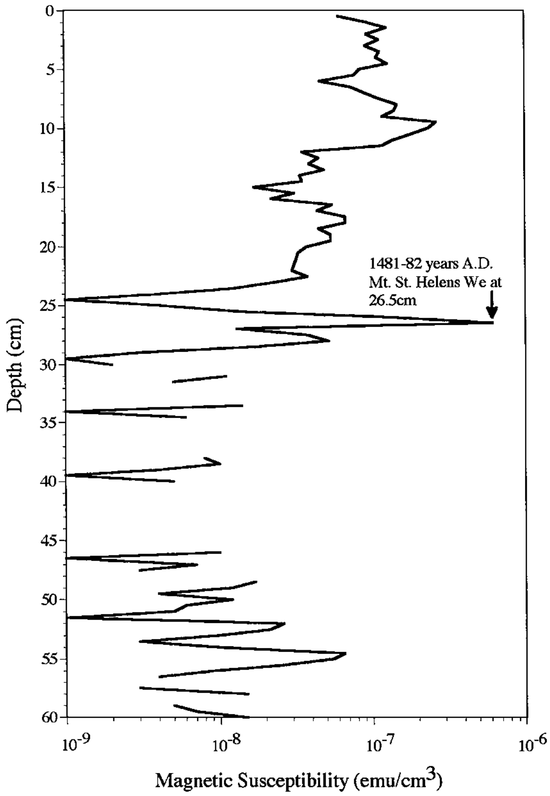

FIG. 3. Plot of magnetic susceptibility data versus depth for the Dog Lake core showing a large peak at 26.5 cm. This large peak indicates the presence of the A.D. 1481–1882. Mount St. Helens We volcanic tephra layer in the sediment.

magnetic susceptibility could be correlated with logged clastic layers in the sediment record. The quartz-rich clastic layers and associated peaks in magnetic susceptibility are likely the product of erosion from fire or flood events affecting the surrounding ferro-humic podzol soils and granitic bedrock (Thompson and Oldfield, 1986).

Peaks in magnetic susceptibility at 127 cm in the FL and at 239 cm in the MBC cores (Fig. 2b) were associated with significant amounts of pumice rather than other clastic material. Pumice fragments were separated from the sieved residue and prepared for scanning electron imaging and electron microprobe analysis. The glass in both Frozen Lake and Mount Barr Cirque Lake was mainly in the form of thick-walled pumice (Figs. 4a and 4b) with green hornblende occasionally attached or included. The only discernable difference between the two tephras was the size of the pumice fragments. In the MBC sample at 239 cm, the maximum length of the pumice fragments averaged approximately 220 μm with a maximum length of 440 μm, whereas in the FL sample at 127 cm, the average was 170 μm and the maximum was 300 μm. The composition of the glasses in FL 127 cm and MBC 239 cm are extremely similar (Table 1), as reflected in a similarity coefficient of 0.99 (Table 3).

Simple linear interpolations using the closest bracketing AMS dates from the age–depth curve for each lake were used to assess the age of each tephra-containing layer. The interpolation for the FL core (Fig. 5a) was constructed using bracketing dates on a conifer needle at 119 cm (4530 $\pm$ 50 ^{14}C yr B.P. CAMS-45984) and a twig fragment at 147 cm (6170 $\pm$ 40 ^{14}C yr B.P. CAMS-45985). The interpolation for the MBC core (Fig. 5b)

TABLE 1
Glass Compositions of Glacier Peak Tephras in the Frozen Lake and Mount Barr Cirque Lake Cores and Glacier Peak Standard Tephras

% Oxides[a]	Frozen Lake Depth = 127 cm	Mount Barr Cirque Lake Depth = 239 cm	Glacier Peak B, M, and G tephra standards: E. Wenatchee[c]	UA422[d]	Grand mean[e]	Range[f]
SiO_2	78.14(0.16)	78.24(0.12)	77.41(0.30)	77.52	77.13(0.33)	76.41–77.73
TiO_2	0.18(0.02)	0.19(0.02)	0.20(0.06)	0.19	0.21(0.02)	0.19–0.25
Al_2O_3	12.19(0.08)	12.15(0.08)	12.42(0.20)	12.55	12.79(0.21)	12.42–13.19
Fe_2O_3	1.03(0.03)	1.03(0.02)	1.07(0.10)	1.04	1.24(0.10)	1.04–1.57
MgO	0.16(0.02)	0.16(0.03)	0.19(0.04)	0.27	0.28(0.06)	0.19–0.43
CaO	0.94(0.04)	0.93(0.03)	1.06(0.03)	0.93	1.28(0.11)	0.93–1.48
Na_2O	3.52(0.08)	3.51(0.06)	3.69(0.10)	3.91	3.72(0.29)	2.97–4.14
K_2O	3.68(0.06)	3.65(0.06)	3.51(0.22)	3.40	3.18(0.20)	2.91–3.69
Cl	0.15(0.02)	0.14(0.01)	0.15(0.05)	0.15	0.17(0.03)	0.11–0.24
Number[b]	16	16	25	not given	40	40
Analytical total	98.03(0.83)	98.29(0.82)	96.64(1.43)	95.51	nd[g]	nd

[a] Analyses normalized to 100% on a water-free basis. Standard errors given in parentheses.
[b] Number of glass shards analyzed.
[c] Glacier Peak tephra from East Wenatchee, Washington (Foit *et al.*, 1993).
[d] Sample UA422 of Glacier Peak tephra (Westgate and Evans, 1978).
[e] Mean oxide weight percents for 40 analyses of well-characterized Glacier Peak tephras. Glass compositions of the B, M, and G tephras are lumped together because they are indistinguishable using electron microprobe analysis.
[f] Range of oxide weight percents for 40 well-characterized Glacier Peak tephras.
[g] Not determined.

TABLE 2
Glass Compositions of Tephra in the Dog Lake Core and Mount St. Helens Standard Tephras

% Oxides[a]	Dog Lake Depth = 26.5 cm	Mount St. Helens standards Wn[c]	Wn[d]	We[e]	We[d]
SiO_2	76.47(0.46)	75.30(0.19)	75.39	75.81(0.44)	75.64
TiO_2	0.21(0.02)	0.20(0.02)	0.19	0.25(0.02)	0.26
Al_2O_3	13.43(0.22)	14.24(0.13)	14.26	13.47(0.24)	13.74
Fe_2O_3	1.58(0.07)	1.80(0.04)	1.73	1.65(0.10)	1.53
MgO	0.24(0.03)	0.33(0.02)	0.32	0.26(0.06)	0.25
CaO	1.33(0.14)	1.65(0.05)	1.63	1.39(0.17)	1.37
Na_2O	4.19(0.17)	4.09(0.21)	4.06	4.52(0.13)	4.67
K_2O	2.43(0.09)	2.31(0.04)	2.29	2.56(0.13)	2.37
Cl	0.09(0.02)	0.09(0.02)	0.1	0.09(0.03)	0.08
Number[b]	22	25	not given	17	not given
Analytical total	97.65(1.10)	97.30(2.74)	98.16	97.47(0.71)	98.22
Similarity coefficient[f]		0.92	0.92	0.96	0.96

[a] Analyses normalized to 100% on a water-free basis. Standard errors given in parentheses.
[b] Number of glass shards analyzed.
[c] Mount St Helens Wn sample 92565-19 obtained from D. Mullineaux.
[d] Sarna-Wojcicki *et al*. (1983).
[e] We tephra from Forlorn Bog, Washington (45°58′ N latitude, 121°46′ W longitude).
[f] Similarity coefficient (Borchardt *et al*., 1972).

was based on conifer needles found at 196 cm (3890 ± 50 ^{14}C yr B.P. CAMS-53983) and 247 cm (5310 ± 50 ^{14}C yr B.P. CAMS-53984). These interpolations yield an approximate age of 5000–5080 ^{14}C yr B.P. with a calibrated age range of ∼5500–5900 cal yr B.P. (Stuiver *et al.*, 1998) for the airfall deposit.

Dog Lake

The core from Dog Lake was sampled in 0.5-cm increments using a close interval sectioning device (Glew, 1988). Magnetic susceptibility readings from this core revealed a large sharp peak at 26.5 cm (Fig. 3). Although not obvious as a tephra layer, the sieved residue from this sample layer contained a high concentration of pumice fragments. The pumice averaged approximately 100 μm in maximum dimension, with a maximum length of 200 μm. The pumice occasionally hosted hypersthene and plagioclase euhedra. The composition of the glass (Table 2) more closely matches that found in Mount St. Helens We tephra (similarity coefficient = 0.96) than the Wn tephra (similarity coefficient = 0.92).

TABLE 3
Matrix of Similarity Ceofficients for Frozen Lake (FL), Mount Barr Cirque Lake (MBC), and Glacier Peak Standard Tephras

	FL 127 cm	MBC 239 cm	E. Wenatchee	UA422	Grand mean
FL 127 cm	1.00				
MBC 239 cm	0.99	1.00			
E. Wenatchee	0.95	0.95	1.00		
UA422	0.95	0.95	0.95	1.00	
Grand mean	0.87	0.87	0.92	0.91	1.00

DISCUSSION

Based on microscopic similarity, nearly identical glass compositions, and interpolated radiocarbon ages, it is very likely that the FL 127-cm and MBC 239-cm tephra layers are associated with the same eruption. A search of the database of tephra glass compositions in the Microbeam Facility (GeoAnalytical Laboratory, Department of Geology, Washington Sate University) yielded best matches (similarity coefficients = 0.95, Table 3) to several well-documented samples of tephra from the 11,200 ^{14}C yr B.P. Glacier Peak eruption, suggesting Glacier Peak as the likely source for the Frozen Lake and Mount Barr Cirque Lake tephras. Although this represents an unusual northwest trajectory for a tephra plume from Glacier Peak (the 11,200 ^{14}C yr B.P. B, M, and G tephras were carried to east, southeast, and northeast), other lines of evidence also support Glacier Peak and discount other volcanoes as the potential source for this tephra. The mean and maximum size of the pumice fragments decrease (downwind) from Mount Barr Cirque Lake to Frozen Lake, which suggests a southerly source for the tephra. Beget (1982, 1984) reports the existence of two mid-Holocene Glacier Peak tephra assemblages, Set D and the thicker Dusty Creek which overlies it. These deposits are typically 5–15 and 20–100 cm thick, respectively, within 10 km of Glacier Peak. Their inferred ages of 5100–6700 and 5100–5500 ^{14}C yr B.P. (Beget, 1984) are nearly coincident with the interpolated ages of both the Frozen Lake and Mount Barr Cirque Lake tephras.

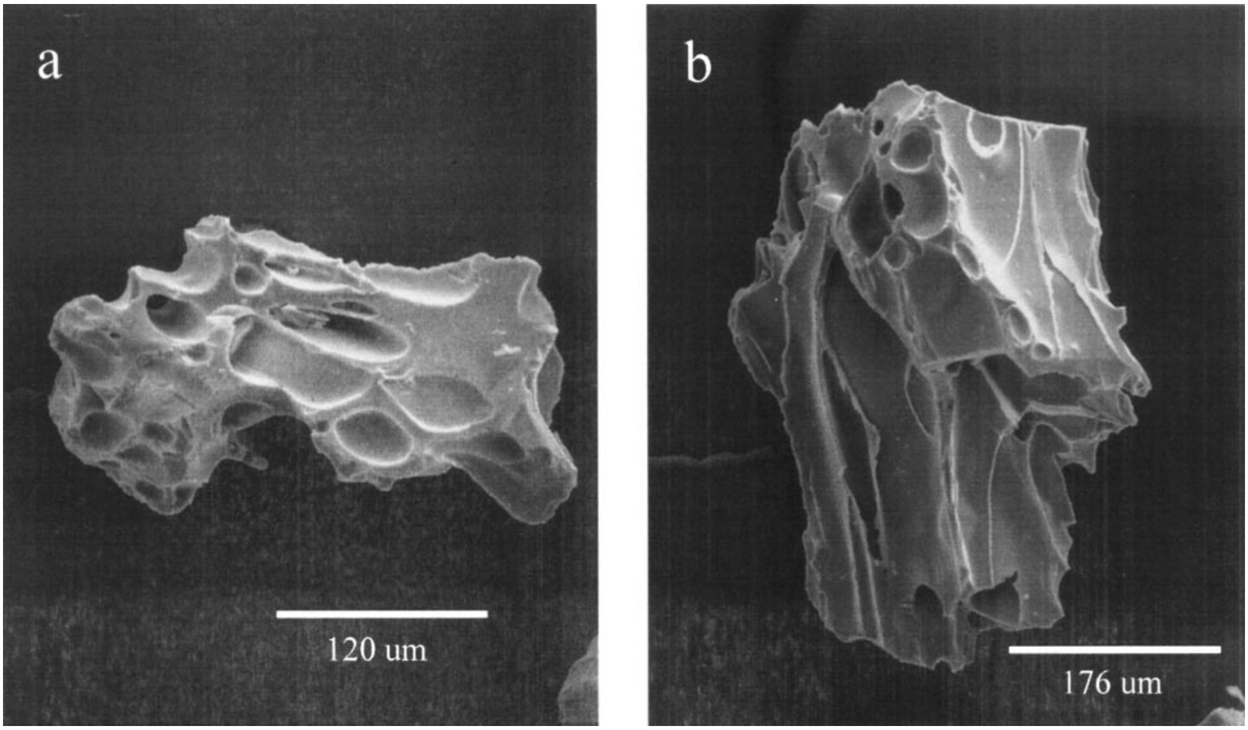

FIG. 4. SEM photographs of (a) Frozen Lake Glacier Peak tephra from a depth of 127 cm and (b) Mount Barr Cirque Lake Glacier Peak tephra from a depth of 239 cm . Bar indicates scale in μm micrometers.

The interpolated age of 5000–5080 ^{14}C yr B.P. for the Frozen Lake and Mount Barr Cirque tephras falls at the younger limit of the inferred ages of the Set D and Dusty Creek tephras. This suggests a closer association with the eruption responsible for the more voluminous and younger Dusty Creek assemblage. Unfortunately, samples of Set D and Dusty Creek tephra were not available (J. E. Beget, personal communication, 2000) for analysis and comparison.

What is known of the other Cascade volcanoes rules them out as a source of the Frozen Lake and Mount Barr Cirque

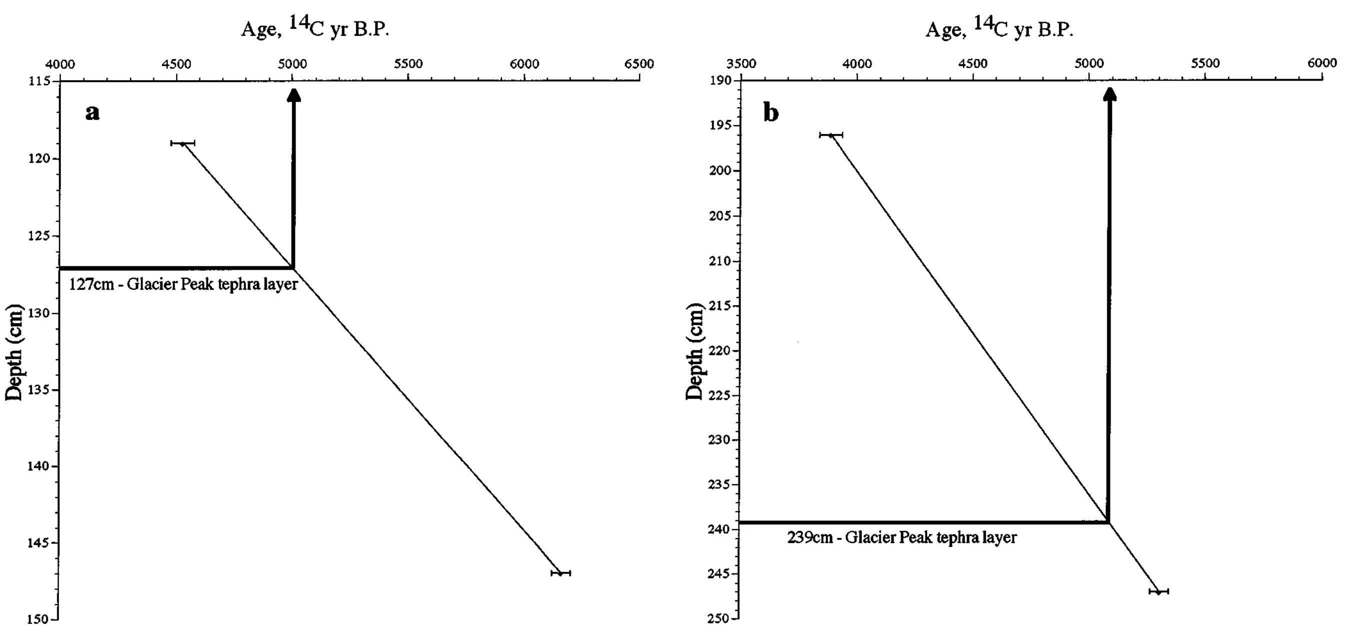

FIG. 5. Age–depth relationships with AMS radiocarbon ages bracketing the mid-Holocene Glacier Peak tephra layer found in (a) Frozen Lake and (b) Mount Barr Cirque Lake.

Lake tephras. Although Mount Baker lies less than 90 km to the southwest and was active during the Holocene (Hyde and Crandell, 1978), the interpolated ages of the MBC and FL tephras do not match any known postglacial events at the mountain. Furthermore, the tephras associated with the two major postglacial eruptions (10,350 and ~6600 ^{14}C yr B.P.) have glass compositions considerably more mafic (F. F. Foit and B. Mierendorf, unpublished data) than those of FL 127 and MBC 239. Although the glass compositions of late-Holocene Mount St. Helens tephras are similar to those of Glacier Peak and those in the FL 127 and MBC 239 tephras, the mid-Holocene was a period of inactivity at Mount St. Helens. Furthermore, the increased distance of Mount St. Helens from southern British Columbia makes it likely that a mid-Holocene tephra would have been observed previously along this long plume track.

The FL 127 and MBC 239 tephra appears to be from the close of the mid-Holocene eruption period of Glacier Peak, which is responsible for the Dusty Creek tephra assemblage found on the flank of the volcano. Closer bracketing AMS dates are needed to increase confidence in age estimates for this mid-Holocene tephra layer. Beget's (1982) ages for the Dusty Creek deposit are from charred logs and must be considered a maximum age for the eruption based on the potential for an old wood effect. More lakes in the region should contain this tephra layer and additional sites would help to define of the aerial extent of the ash plume.

Although Dog Lake lies in the general direction of the plume track (Sarna-Wojcicki *et al.*, 1983) for the A.D. 1479–1480 Mount St. Helens Wn tephra and is far north of the later A.D. 1481–1482 (Yamaguchi, 1985) We plume track, the composition of the glass in tephra found at a depth of 26.5 cm is a significantly better match to that in the Mount St. Helens We tephra (Table 2). The similarity coefficient (Borchardt *et al.*, 1972) between the Wn standard tephras and the Dog Lake tephra is 0.92 whereas that between the We standards and the Dog Lake tephra is 0.96. This suggests that aerial distribution of We tephra may be much broader (more northerly) than is currently thought (Mullineaux, 1986, 1996; Smith *et al.*, 1977). Dog Lake lies on the southern edge of the proposed Wn airfall distribution (Sarna-Wojcicki *et al.*, 1983, 1991), which may explain its apparent absence in the Dog Lake core. More lake sites should contain these tephras and the use high-resolution techniques would better define the extent of the We and Wn ash plumes in western North America. These well-dated stratigraphic markers are important for high-resolution paleoenvironmental studies focusing on the past millennium where radiocarbon-based chronologies become problematic (e.g., Dugmore *et al.*, 1996; Pilcher *et al.*, 1996).

CONCLUSIONS

Use of high-resolution contiguous sampling (0.5–1.0 cm), wet sieving, light microscopy, and magnetic susceptibility measurements on lake sediments are common methods in charcoal-based fire history reconstructions in western North America (Hallett and Walker, 2000; Long *et al.*, 1998; Millspaugh and Whitlock, 1995; Millspaugh *et al.*, 2000; Mohr *et al.*, 2000). These methods have now proven effective in revealing and isolating distinct but invisible tephra layers from the surrounding sediment. Their application to sediment cores from Frozen Lake, Mount Barr Cirque Lake, and Dog Lake has shed new light on the age and airfall distribution of tephras from two important Cascade volcanoes, Mount St. Helens and Glacier Peak. Neither the Glacier Peak Dusty Creek nor the Mount St. Helens We tephras have been previously reported north of the United States–Canada border. The interpolated ages of the Glacier Peak tephras in the Frozen Lake and Mount Barr Cirque Lake cores confirm the proposed age (Beget, 1982, 1984) of the eruptive period responsible for the Dusty Creek assemblage. Mount St. Helens set W tephras are important pre-European stratigraphic markers for paleoenvironmental studies using lake sediments in the region and even for distant ice cores from Greenland (Fiacco *et al.*, 1993).

Examination of additional subalpine lakes with laminated sediment records and AMS datable plant macrofossils would greatly further our knowledge of regional tephra stratigraphy and chronology. A broad distribution of lake sites with tephra layers would form the basis for global studies of major volcanic eruptions. As demonstrated by the studies of GISP2 ice cores, a tightly constrained tephra-based chronology is essential to global studies of major volcanic eruptions and potential links to global climate change (Zdanowicz *et al.*, 1999; Zielinski *et al.*, 1994). Large explosive eruptions from Cascade volcanoes have contributed to variable Northern Hemispheric cooling in the past 600 years (Briffa *et al.*, 1998).

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