New accelerator mass spectrometry radiocarbon ages for the Mazama tephra layer from Kootenay National Park, British Columbia, Canada[1]

D.J. Hallett, L.V. Hills, and J.J. Clague

Abstract: Charcoal fragments recovered from the Mazama air-fall tephra layer in cores from Dog and Cobb lakes, Kootenay National Park, British Columbia, yielded accelerator mass spectrometry ages of 6720 ± 70 and 6760 ± 70 ^{14}C years BP, respectively. These two new ages, together with other previously published radiocarbon ages on charcoal and twig fragments from Mazama air-fall deposits, indicate that the climactic eruption of Mount Mazama occurred 6730 ± 40 ^{14}C years BP.

Résumé : Les morceaux de charbon recueillis dans les carottes de la couche des retombées aériennes du tephra de Mazama aux lacs Dog et Cobb, du Parc national de Kootenay, en Colombie-Britannique, ont fourni des âges par accélérateur de particules de 6720 ± 70 et 6760 ± 70 années ^{14}C Av. P., respectivement. Ces deux âges nouveaux, joints à d'autres âges au radiocarbone sur morceaux de charbon et de petites branches publiés auparavant, indiquent que la phase culminante de l'éruption du mont Mazama date de 6730 ± 40 années ^{14}C Av. P.
[Traduit par la rédaction]

Introduction

Late Pleistocene and Holocene tephra layers in western Canada and the northwestern United States are important stratigraphic markers that provide archaeologists, geologists, volcanologists, physical geographers, and paleoecologists with chronological control on past events (Sarna-Wojcicki et al. 1983, 1991; Sarna-Wojcicki and Davis 1991). The most widespread and important of these tephra layers was produced by the climactic eruption of Mount Mazama (Crater Lake, Oregon) about 6845 ± 50 ^{14}C years BP (Bacon 1983). During this eruption, tephra was carried up to 2000 km north and east from the source vent, and covered more than 1 000 000 km^2 of western North America (Fig. 1) (Sarna-Wojcicki et al. 1983; Nelson et al. 1988; Sarna-Wojcicki and Davis 1991).

In this paper, we report two new accelerator mass spectrometry (AMS) radiocarbon ages that precisely date the Mazama tephra layer in British Columbia, and thus provide new age data on the eruptive event. We also review previously published Mazama radiocarbon ages and present a new weighted mean age for the climactic eruption.

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D.J. Hallett.[2] Department of Biological Sciences, Simon Fraser University, Burnaby, BC V5A 1S6, Canada.
L.V. Hills. Department of Geology and Geophysics, The University of Calgary, 2500 University Drive NW, Calgary, AB T2N 1N4, Canada.
J.J. Clague. Geological Survey of Canada, Suite 101, 605 Robson Street, Vancouver, BC V6B 5J3, Canada, and Department of Earth Sciences, Simon Fraser University, Burnaby, BC V5A 1S6, Canada.

[1] Geological Survey of Canada Contribution 1996268.
[2] Corresponding author (e-mail: dhallett@sfu.ca).

Published radiocarbon ages

Many radiocarbon ages have been obtained on fossil plant material associated with deposits of the Mazama eruption, for example, charred wood fragments within ash-flow deposits near Crater Lake, and plant remains above and below Mazama tephra layer in bogs and lakes farther from the source (Table 1). Most of these radiocarbon ages, however, do not precisely date the eruption; rather, they are maximum or minimum ages (Table 1). A radiocarbon age on peat directly below tephra, for example, is a maximum for the time of eruption. Charred wood in Mazama ash-flow deposits is generally assumed to closely date the eruption (Kittleman 1973), but wood entrained by turbulent pyroclastic flows may be reworked or it may come from the interior of a living tree, in which case it may be tens or even hundreds of years older than the eruption.

Some of the radiocarbon ages reported in Table 1 are probably in error because the dated material contains old carbon. Marl, calcareous gyttja, aquatic mosses, and some other limnic sediments are subject to this problem, and may give radiocarbon ages up to several hundred years too old (Mathewes and Westgate 1980; Nambudiri et al. 1980; Turner et al. 1983; White et al. 1985; MacDonald et al. 1987, 1991). Peat free of aquatic mosses is not likely to suffer old carbon effects, but it may still contain reworked plant detritus that is older than the dated deposit. This may account for the considerable difference between some of the peat and wood–charcoal dates in Table 1. In general, bulk sediment ages reported in Table 1 should not be considered as reliable as ages on identified plant macrofossils.

The best material for dating the Mazama eruption is the outermost rings of rooted trees killed by a pyroclastic flow or tephra fall. However, to our knowledge such tree remains have not been found or dated (see, however, Clague et al. (1995) for an application to other volcanic eruptions in western North America). Some Mazama air-fall tephra deposits contain charcoal derived from vegetation that was burned by forest fires during the eruption. Radiocarbon ages on such charcoal will closely date the eruption, as long as the charcoal comes from the bark and outer rings of trees or from other photosynthetically active plant material.

Bacon's (1983) work at Crater Lake has yielded the most commonly cited date for the Mazama eruption, 6845 ± 50 ^{14}C years BP.[3] This is a weighted mean age based on four radiocarbon ages on charcoal and wood collected from ash-flow and air-fall deposits (Table 1). Here, we report a new weighted mean age for the eruption based solely on radiocarbon ages on charcoal and twig remains recovered from the air-fall tephra layer.

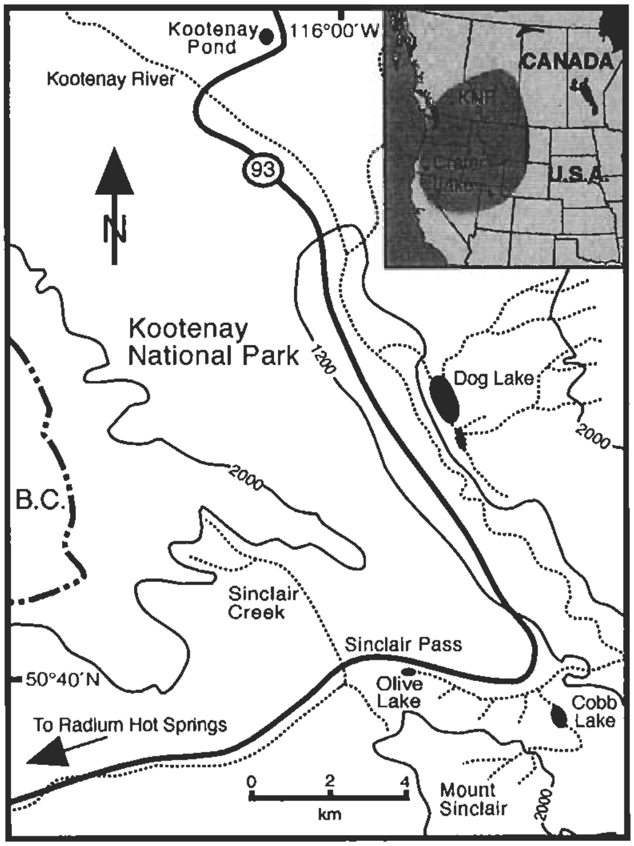


Fig. 1. Map of the Kootenay Valley showing the locations of Dog Lake, Cobb Lake, and Kootenay Pond. The inset shows the minimum extent of the Mazama tephra layer in western North America (after Sarna-Wojcicki et al. 1983; Sarna-Wojcicki and Davis 1991). KNP, Kootenay National Park.

Mazama tephra in the Kootenay Valley, British Columbia

Three lakes were cored in Kootenay National Park as a part of a palynological and fire-history study of the Kootenay Valley. Cores from Dog (15.1 ha) and Cobb (2.1 ha) lakes (Fig. 1) contain a conspicuous layer of charcoal-bearing tephra (Fig. 2). Trace amounts of very fine charcoal (20–300 μm) were also present in tephra in a third core taken from Kootenay Pond (2.6 ha), 15 km upvalley from Dog Lake (Fig. 1). Microprobe analysis of glass shards, using the methods of Smith and Westgate (1969) and Westgate and Fulton (1975), confirms that the tephra layer in the Dog and Cobb lake cores is Mazama (Fig. 3) (L. Gerloff, written communication, 1996).

Large pieces (300 μm – 5 mm) of charcoal in the Dog and Cobb lake cores were dated at the accelerator mass spectrometry facility at the University of Toronto (IsoTrace Radiocarbon Laboratory). The Dog Lake charcoal yielded an age of 6720 ± 70 ^{14}C years BP (TO-5192), and the Cobb Lake charcoal gave a nearly identical age of 6760 ± 70 ^{14}C years BP (TO-5196) (Fig. 4; Table 1; 1σ uncertainties). These ages are also similar to two other Mazama air-fall tephra layer ages reported by Fulton (1971) and Bacon (1983), namely 6560 ± 115 ^{14}C years BP (I-3809) and 6840 ± 100 ^{14}C years BP (W-4295). The weighted mean of all four ages is 6730 ± 40 ^{14}C years BP (Fig. 4; 1σ uncertainty). The corresponding calendric age range (2σ), calculated using the calibration program of Stuiver and Reimer (1993) and an error multiplier of 1, is 7470–7620 cal years BP.[4]

Figure 5 compares the four Mazama air-fall tephra layer ages, and their weighted mean, with the maximum and minimum ages listed in Table 1. Ages associated with the older Llao Rock event (Tsoyowata ash bed; see Table 1) are excluded from the plot. It can be seen from Fig. 5 that some of the means of maximum ages are younger than the weighted mean of the four air-fall ages; however, only one maximum age (6390 ± 160 ^{14}C years BP) is significantly younger than the weighted mean at the 2σ level. Similarly, some means of minimum ages are older than the weighted mean, but only one minimum age (7980 ± 220 ^{14}C years BP) is significantly older than the weighted mean at the 2σ level. The anomalous minimum age is probably too old because of an old carbon effect or because the tephra layer settled into the dated gyttja (White and Osborn 1992). The bracketing ages plotted in Fig. 5 are thus consistent with, and provide support for, the air-fall tephra layer ages.

Discussion

The dated charcoal from Dog and Cobb lakes was deposited during a large forest fire that coincided with the Mazama tephra fall. The high concentration of particulate matter in the atmosphere during the eruption probably caused intense convective storms and lightning strikes that triggered wildfires throughout western North America. Wind-driven crown fires consume the fine fuel components of trees, such as needles, branches, and cambial layer (Albini 1993), leaving charred tree stems and stumps in their wake. Airborne charcoal particles produced by such fires are common in lacustrine deposits (Patterson et al. 1987; Clark 1988), and would be expected to yield radiocarbon ages very close to the time of tephra deposition and hence the eruption. The statistical equivalence of the Dog and Cobb lake AMS ages, obtained from sites 10 km apart, supports the idea that a wildfire swept through the Kootenay Valley during the climactic eruption of Mount Mazama. Either the same forest fire or,

[3] All radiocarbon ages in this paper are in radiocarbon years before present AD 1950.

[4] Error multipliers expand laboratory-quoted errors to cover uncertainties in reproducibility and systematic bias; for a full discussion, see Stuiver and Pearson (1993).

Table 1. Summary of published radiocarbon ages for Mazama tephra.

Radiocarbon age (^{14}C years BP)[a]	Laboratory No.[b]	Location: Lat. N	Location: Long. W	Dated material	Reference	Locality	Comment
5500±140	GSC-1183	51°04′	118°04′	Peat above tephra	Lowdon et al. 1971	Mount Revelstoke, B.C.	Minimum age of tephra
5550±120	I-3807	52°06′	118°33′	Wood above tephra	Fulton 1971	Columbia River Valley, B.C.	Minimum age of tephra
6560±115	I-3809			Charcoal within tephra			Age of tephra
5950±400	W-779	47°26′	122°18′	Peat above tephra	Rubin and Alexander 1960	Bow Lake, Wash.	Minimum age of tephra
6020±90	S-191	51°55′	116°50′	Bulk sample of paleosol and charcoal associated with tephra	Westgate and Dreimanis 1967	North Saskatchewan River, Alta.	Minimum age of tephra
6190±120	I-3158	52°00′	118°30′	Charcoal above tephra	Buckley and Willis 1969	Columbia River, B.C.	Minimum age of tephra
7670±220	I-3159			Charcoal 30 cm below tephra			Maximum age of tephra
6270±140	GSC-214	50°23′	119°16′	Organic muck above tephra	Dyck et al. 1965	Deep Creek, B.C.	Minimum age of tephra
7510±150	GSC-206			Organic muck below tephra			Maximum age of tephra
6350±230	TX-2121	48°45′	117°00′	Coarse gyttja above tephra	Mack et al. 1978	Hagar Pond, Idaho	Minimum age of tephra
6630±80	TX-2116			Algal gyttja below tephra			Maximum age of tephra
6390±160	GSC-963	48°27′	123°29′	Gyttja below tephra	Lowdon and Blake 1970	Rithets Bog, Vancouver Island, B.C.	Maximum age of tephra
6420±110	QL-1434	46°35′	122°15′	Fine gyttja above tephra	Barnosky 1981	Davis Lake, Wash.	Minimum age of tephra
7460±120	QL-1435			Fine gyttja below tephra			Maximum age of tephra
6453±250	C-247	42°50′	122°10′	Charcoal from trees buried by ash-flow deposit	Arnold and Libby 1951	Muir Creek, Oreg.	Average of four ages, replicate of M-21, minimum age of ash flow
6470±100	RIDDL-1058	49°20′	122°30′	Pollen concentrate above tephra	Brown et al. 1989	Mike Lake, B.C.	Minimum and maximum ages of tephra, weighted mean is 6480 ± 60 ^{14}C years BP
6470±170	RIDDL-1059			Pollen concentrate above tephra			
6490±80	RIDDL-1057			Pollen concentrate below tephra			
6500±200	L-269C	47°21′	122°04′	Peat below tephra	Broecker et al. 1956	Covington, Wash.	Maximum age of tephra
6500±500	M-21	42°50′	122°10′	Charcoal from trees buried by ash-flow deposit	Crane 1956	Crater Lake, Oreg.	Average of two ages, replicate of C-247, minimum age of ash flow
6570±70	GSC-2648	52°30′	118°20′	Log above tephra	Luckman et al. 1986	Tonquin Pass, B.C.	Minimum age of tephra
6600±400	W-776	47°25′	122°21′	Peat below tephra	Rubin and Alexander 1960	Arrow Lake, Wash.	Maximum age of tephra
6630±400	W-777						
6640±250	W-858	43°20′	122°42′	Charcoal in pumice deposit	Rubin and Alexander 1960	Toketee Falls, Oreg.	Age of pumice deposit
6670±120	I-3674	48°27′	123°25′	Peat above tephra	Buckley and Willis 1970	Portage Inlet, Vancouver Island, B.C.	Minimum age of tephra
6700±100	WSU-1552	45°40′	114°11′	Limnic sediment above tephra	Mehringer et al. 1977	Lost Trail Pass Bog, Mont.	Minimum age of tephra
6720±120	WSU-1553			Limnic sediment below tephra			Maximum age of tephra
6710±110	TX-2597	41°40′	119°11′	Charcoal and wood below tephra	Davis 1978	Virgin Creek, Nev.	Maximum age of tephra
6720±70	TO-5192	50°45′	116°10′	Charcoal within tephra	This paper	Dog Lake, Kootenay National Park, B.C.	Age of tephra
6730±250	W-2422	46°55′	121°45′	Organic material above tephra	Mullineaux 1974	Mount Rainier National Park, Wash.	Minimum age of tephra
6760±70	TO-5196	50°40′	116°10′	Charcoal within tephra	This paper	Cobb Lake, Kootenay National Park, B.C.	Age of tephra
6780±100	W-4288	43°15′	122°25′	Charcoal in ash-flow deposit	Bacon 1983	Roadcuts along Oregon Hwy. 138	Overlies flow unit of W-4290, minimum age of tephra
6810±190	TX-2882	48°50′	119°02′	Peat above upper tephra	Mack et al. 1979	Bonaparte Meadows, Wash.	Climactic eruption according to Bacon 1983, minimum and maximum age of tephra
6870±110	TX-2881			Peat below upper tephra			
6830±110	W-4290	43°15′	122°25′	Charcoal in ash-flow deposit	Bacon 1983	Roadcuts along Oregon Hwy. 138	Minimum age of tephra
6840±100	W-4295	43°15′	122°21′	Twig within tephra	Bacon 1983	Roadcuts along Oregon Hwy. 138	Tephra overlain by flow unit of W-4255, age of tephra
6850±140	BGS-1098	51°15′	115°55′	Gyttja above tephra	White and Osborn 1992	Copper Lake, Banff National Park, Alta.	Ages too old due to old carbon effect, settling of tephra into gyttja
7980±220	BGS-1084			Gyttja above tephra			

Table 1 (*concluded*).

Radiocarbon age (^{14}C years BP)[a]	Laboratory No.[b]	Location Lat. N	Location Long. W	Dated material	Reference	Locality	Comment
6860±60	RIDDL-647	49°20′	122°30′	Limnic sediment above tephra	Brown et al. 1989	Mike Lake, B.C.	Ages too old due to contamination
7080±60	RIDDL-648			Limnic sediment below tephra			
6880±70	W-4255	43°15′	122°25′	Branch in ash-flow deposit	Bacon 1983	Roadcuts along Oregon Hwy. 138	Overlain by flow unit of W-4290, minimum age of tephra
6930±110	TX-2883	48°50′	119°02′	Peat above lower tephra	Mack et al. 1979	Bonaparte Meadows, Wash.	Llao Rock eruption according to Bacon 1983; minimum and maximum age of Llao Rock tephra
8300±80	TX-2884			Peat below lower tephra			
6930±135	I-5347	49°29′	121°24′	Gyttja below tephra	Mathewes et al. 1972	Squeah Lake, B.C.	Maximum age of tephra
6940±120	TX-487	43°02′	122°22′	Charcoal from ash-flow deposit	Valastro et al. 1968	Muir Creek, Oreg.	Same charcoal as GaK-1124, maximum age of tephra
6950±200	L-269B	47°25′	122°05′	Peat below tephra	Rigg and Gould 1957	Moss Lake, Wash.	Maximum age of tephra, first reported as 7000 ± 200 ^{14}C years BP by Broecker et al. 1956
6990±300	A-728	38°50′	120°02′	Peat 1 cm below lower tephra	Haynes et al. 1967; Adam 1967	Osgood Swamp, Calif.	Maximum age of Tsoyowata Bed
7000±120	GaK-1124	43°02′	122°22′	Charcoal from ash-flow deposit	Randle et al. 1971	Muir Creek, Oreg.	Same charcoal as TX-487, maximum age of tephra
7000±200	L-269B	47°25′	122°05′	Peat below tephra	Broecker et al. 1956	Moss Lake, Wash.	Maximum age of tephra, later reported as 6950 ± 200 ^{14}C years BP by Rigg and Gould 1957
7010±120	GaK-1124	43°02′	122°22′	Charcoal from ash-flow deposit	Kittleman 1973	Muir Creek, Oreg.	Same charcoal as TX-487, GaK-1124 first reported as 7000 ± 120 ^{14}C years BP by Randle et al. 1971
7190±150	GSC-459	49°33′	121°24′	Charcoal below tephra	Lowdon et al. 1969	Fraser Canyon, B.C.	Maximum age of tephra
7190±150	GSC-1487	50°44′	119°43′	Marl below tephra	Lowdon and Blake 1973	Chase, B.C.	Ages from the same sample but on different fractions; maximum age of tephra
7400±160	GSC-1487-2			Peat below tephra			
7200±200	QL-1513	47°40′	122°14′	Gyttja above tephra	Leopold et al. 1982	Lake Washington, Wash.	Minimum age of tephra layer
6930±110	QL-1514			Gyttja below tephra			Maximum age of tephra layer
7340±360	GSC-321	49°14′	122°57′	Peat below tephra	Dyck et al. 1966	Burnaby Lake, B.C.	Maximum age of tephra
7350±150	S-61	49°33′	121°24′	Charcoal below tephra	McCallum and Dyck 1960	Fraser Canyon, B.C.	Maximum age of tephra
7390±250	GX-4039	51°27′	119°55′	Charcoal below tephra	Duford and Osborn 1978	Dunn Peak, B.C.	Maximum age of tephra
7430±340	GaK-4649	49°10′	122°56′	Charcoal below tephra	Matson 1976	Glenrose Cannery, B.C.	Maximum age of tephra
7530±270	GSC-530	50°22′	121°23′	Charcoal below tephra	Lowdon et al. 1969	Drynoch Slide, B.C.	Maximum age of tephra
7645±340	I-6821	49°19′	122°33′	Gyttja below tephra	Mathewes 1973	Marion Lake, B.C.	Maximum age of tephra
8275±135	I-6966	49°19′	122°34′	Gyttja below tephra	Mathewes 1973	Surprise Lake, B.C.	Maximum age of tephra
8310±150	GSC-875	49°30′	118°05′	Peaty marl below tephra	Lowdon and Blake 1970	Twobit Creek, B.C.	Maximum age of tephra
8320±140	GSC-1004	50°14′	119°01′	Fibrous organic matter below tephra	Lowdon and Blake 1970	Lavington, B.C.	Maximum age of tephra
8380±150	GSC-213	50°23′	119°16′	Plant detritus below tephra	Dyck et al. 1965	Lower Arrow Lake, B.C.	Maximum age of tephra

[a]Laboratory-reported error terms are 2σ for Geological Survey of Canada ages and 1σ for all others. Most ages have been corrected for isotopic fractionation to a base of $\delta^{13}C = -25.0‰$. Many radiocarbon ages from the 1960's, however, were not corrected for fractionation. For most plant materials, these ages would not change much if normalized to −25.0‰.

[b]A, Arizona; BGS, Brock University; C, University of Chicago; GaK, Gakushuin University; GSC, Geological Survey of Canada; GX, Geochron Laboratories; I, Teledyne Isotopes; L, Lamont; M, University of Michigan; QL, University of Washington; RIDDL, Simon Fraser and McMaster universities; S, University of Saskatchewan; TO, University of Toronto; TX, University of Texas; W, United States Geological Survey; WSU, Washington State University.

Fig. 2. Layer of Mazama tephra from the Dog Lake core. Note Mazama–limnic sediment contact (M) and charcoal fragments within the tephra (C).

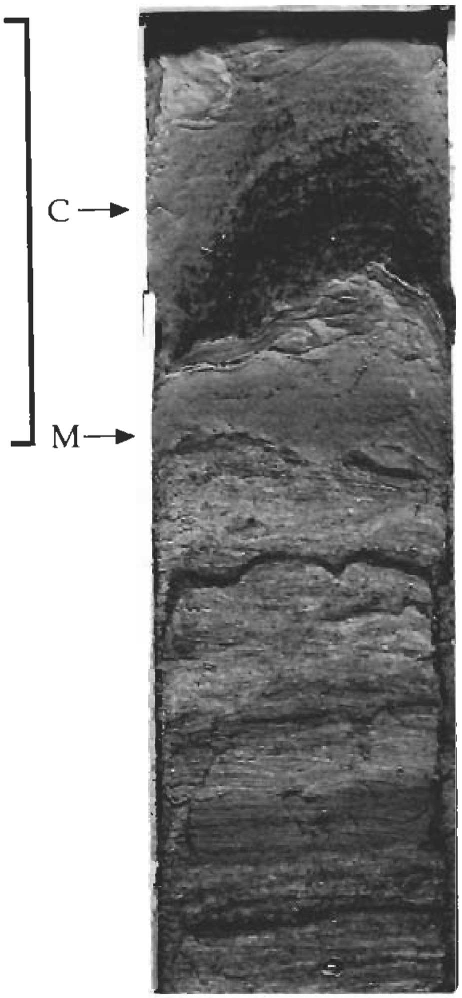


Fig. 3. Chemical composition of glass shards from tephra layers at Dog and Cobb lakes based on microprobe analysis. Compositional fields of common tephra layers in southern Canada are also shown (after Westgate and Evans 1978). The Dog and Cobb lake data shown here are part of a larger multielement data set.

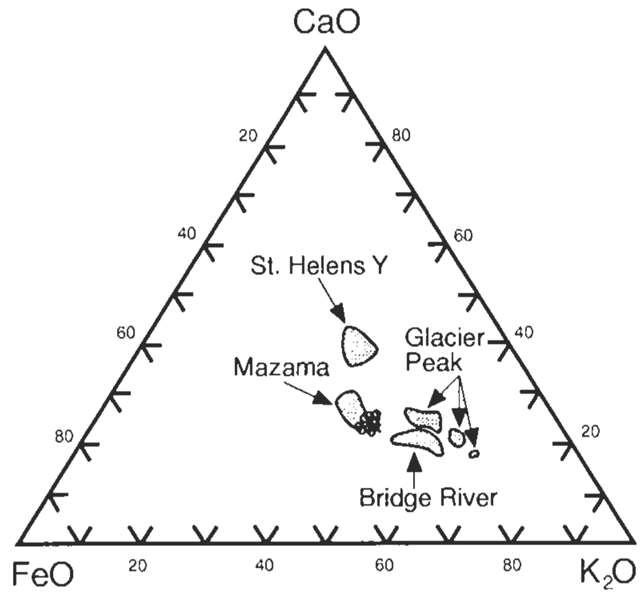
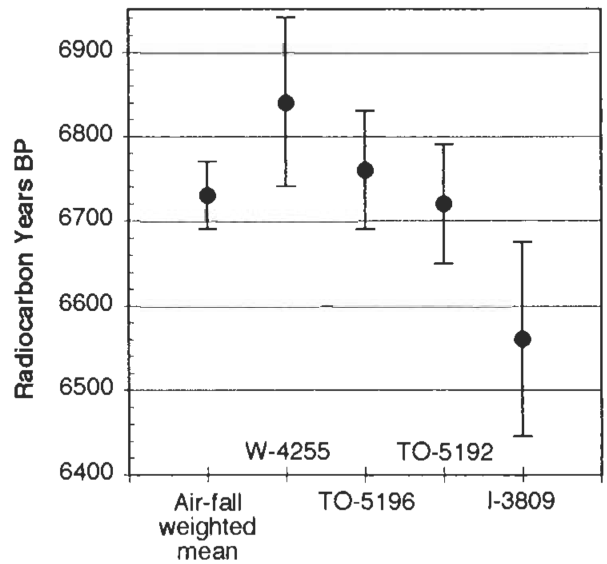


Fig. 4. Radiocarbon ages on charcoal and twig fragments from the Mazama air-fall tephra layer. Vertical bars represent 1σ age ranges.

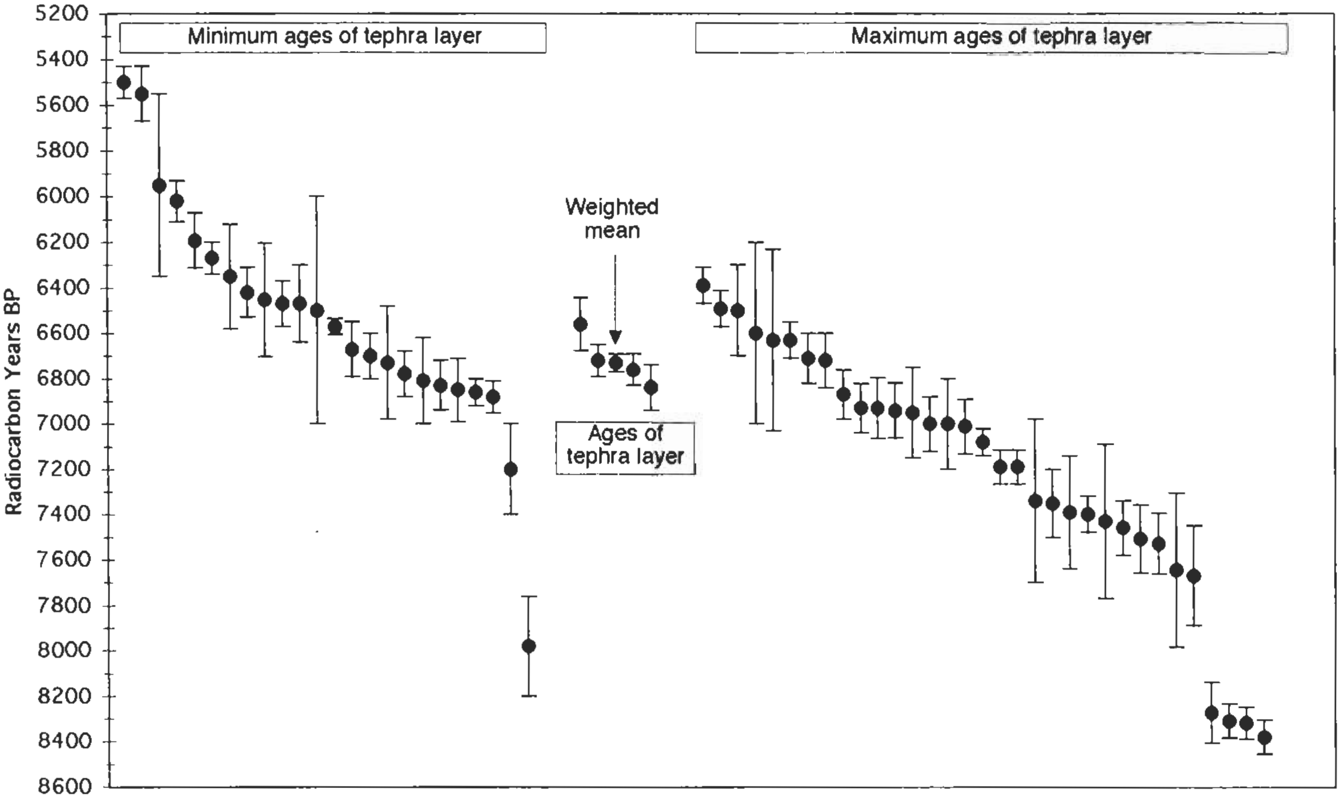


more likely, a separate fire at the same time produced the dated material in Mazama tephra about 230 km to the northwest in the Columbia River valley (Table 1) (Fulton 1971). Mehringer et al. (1977) showed through pollen analysis that the Mazama tephra was deposited in autumn, and forest fire evidence from the Kootenay Valley also supports a late summer or autumn eruption.

Mack et al. (1979) found evidence for two Mazama eruptions at Bonaparte Meadows, in northern Washington State. Radiocarbon ages on peat samples bracketing the upper tephra layer (6810 ± 190 and 6870 ± 110 ^{14}C years BP) are statistically equivalent to the Kootenay Valley AMS ages. Bacon (1983) concluded that the upper tephra layer at Bonaparte Meadows was deposited during the climactic eruption of Mount Mazama and that the lower tephra layer represents a discrete older eruption identified near Crater Lake (the Llao Rock event). The older eruption is also responsible for the Tsoyowata Bed, a tephra layer that underlies the main Mazama tephra layer at many sites in the western United States (Davis 1978). Borchardt et al. (1971, 1973) and Blinman et al. (1979) have also reported two Mazama tephra layers. Only a single tephra layer is present in the Kootenay Valley, indicating that the tephra in that area, which is far from the vent, records the climactic eruption of Mount Mazama.

Some of the wood and charcoal ages in Table 1 (see also Fig. 5) are from ash-flow deposits or from coarse tephra that may or may not be air-fall material. Although these ages are near the time of the Mazama eruption, we have chosen to exclude them from our weighted mean because they may not directly date the eruption. We have also excluded peat and

Fig. 5. Plot of maximum, minimum, and approximate Mazama radiocarbon ages (Table 1). Vertical bars are 1σ age ranges. The maximum and minimum ages bracket the four air-fall tephra layer ages and their weighted mean.



gyttja ages, in part for the same reason and in part because they may be too old due to old carbon effects and reworking. Kittleman (1973) and Bacon (1983) stressed the need to date tephra-enclosed charcoal fragments derived from small twigs and branches to minimize errors in assigning ages to eruptions. We take this recommendation one step further by basing our age assignment entirely on charcoal and twig remains from within the air-fall tephra deposit.

Conclusions

Charcoal fragments recovered from the Mazama tephra layer at Dog and Cobb lakes in Kootenay National Park yielded AMS radiocarbon ages of 6720 $\pm$ 70 and 6760 $\pm$ 70 ^{14}C years BP, respectively. These, along with two additional charcoal and twig ages from other sites, give a weighted mean age of 6730 $\pm$ 40 ^{14}C years BP (7470–7620 cal years BP) for the climactic eruption of Mount Mazama. Charcoal produced by wildfires is composed mainly of burnt foliage, twigs, and outer tissue of trees; its age is thus close to that of the fire. Charcoal is delicate and less likely to be resedimented than wood and thus it can provide accurate radiocarbon ages for tephra layers.

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