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A Late Pleistocene Tephra Layer in the Southern Great Basin and Colorado Plateau Derived from Mono Craters, California

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A newly identified tephra in stratified deposits in southwestern Utah, dated ~14,000 ^{14}C yr B.P., may aid in correlating late Pleistocene deposits across parts of the southern Great Basin and west-central Colorado Plateau. Geochemical analyses of the ash suggest the tephra originated from Mono Craters, California, and most probably correlates with Wilson Creek ash #3. Because the ash is 2 mm thick ~550 km from its source, the event may have been larger than others correlated to Mono Craters eruptions. © 2002 University of Washington.

Key Words: **Quaternary; tephra; Great Basin; Colorado Plateau; Mono Craters.**

INTRODUCTION

This article describes the physical characteristics, chemical composition, and age of a late Pleistocene volcanic ash from the Markagunt Plateau, Utah. The ash was found in a core from Lowder Creek bog taken to provide a limiting age for deglaciation of the plateau (Mulvey *et al*., 1984). We obtained additional cores that contain the reported tephra layer bounded by organic-rich lake deposits.

The Markagunt Plateau, at an elevation of above 3000–3400 m, lies in the transition between the Great Basin and the Colorado Plateau (Figs. 1 and 2). Late Wisconsin glaciers formed in shallow valley heads along the southeastern margin of Brian Head (3446 m) and Sidney Peaks, the highest points on the plateau. Lowder Creek bog lies in a small moraine-dammed basin near the midpoint of the Lowder Creek glacier (UTM: 342040 easting, 4170790 northing, zone 12; NE 1/4, NW 1/4, NE 1/4, Section 19, T36S, R8E; Brian Head 7.5′ quadrangle).

Beneath the bog, laminated lacustrine silty clay is overlain by sedge peat. During the first 5000–6000 yr of its ~17,000-^{14}C-yr history, Lowder Creek bog was a small, open, shallow lake fringed with sedges. By ~9000 ^{14}C yr B.P., sedges covered this former lake area. The tephra reported by Mulvey *et al*. (1984) was in the lacustrine clay at a depth of 6.12–6.25 m, ~50–150 cm above the basal gravel of Lowder Creek glacial till. (Multiple cores taken at various locations in the bog produced slightly different depth measurements.) Using a hand-driven piston corer 5 cm in diameter, we collected two cores ~10 m apart in 1997 and 1998 (#1 and #2) from locations near those from which the earlier cores were taken. In both cases, we found what appears to be the ash reported by Mulvey *et al*. (1984).

STRATIGRAPHY AND PETROGRAPHY

The tephra layers in the cores are thin, light gray, and fine grained (very fine sand and silt). The lower layer is 2 mm thick, tabular, pure, and uniform in grain size (Table 1, BH-DM-1). The upper layer is composed of several very thin (<1 mm) laminae of ash that contain variable amounts of detrital sediment and tephra from one lamina to the next (Table 1, BH-DM-1). The stratigraphic characteristics and order of the two thin tephra layers in the cores, as well as their essentially identical chemical compositions, suggest that the lower, 2-mm-thick tephra layer formed by direct air fall of ash into the lake. The 8-mm-thick compound layer apparently resulted from several episodes of reworking of the ash by tributaries to the pond.

The volcanic ash layers are composed of ~80% pumiceous glass shards with spindle-shaped vesicles or pipe-shaped capillaries. The shards are angular and unaltered. The ash contains about 10% biotite, 5% volcanic lithic fragments, and 5%

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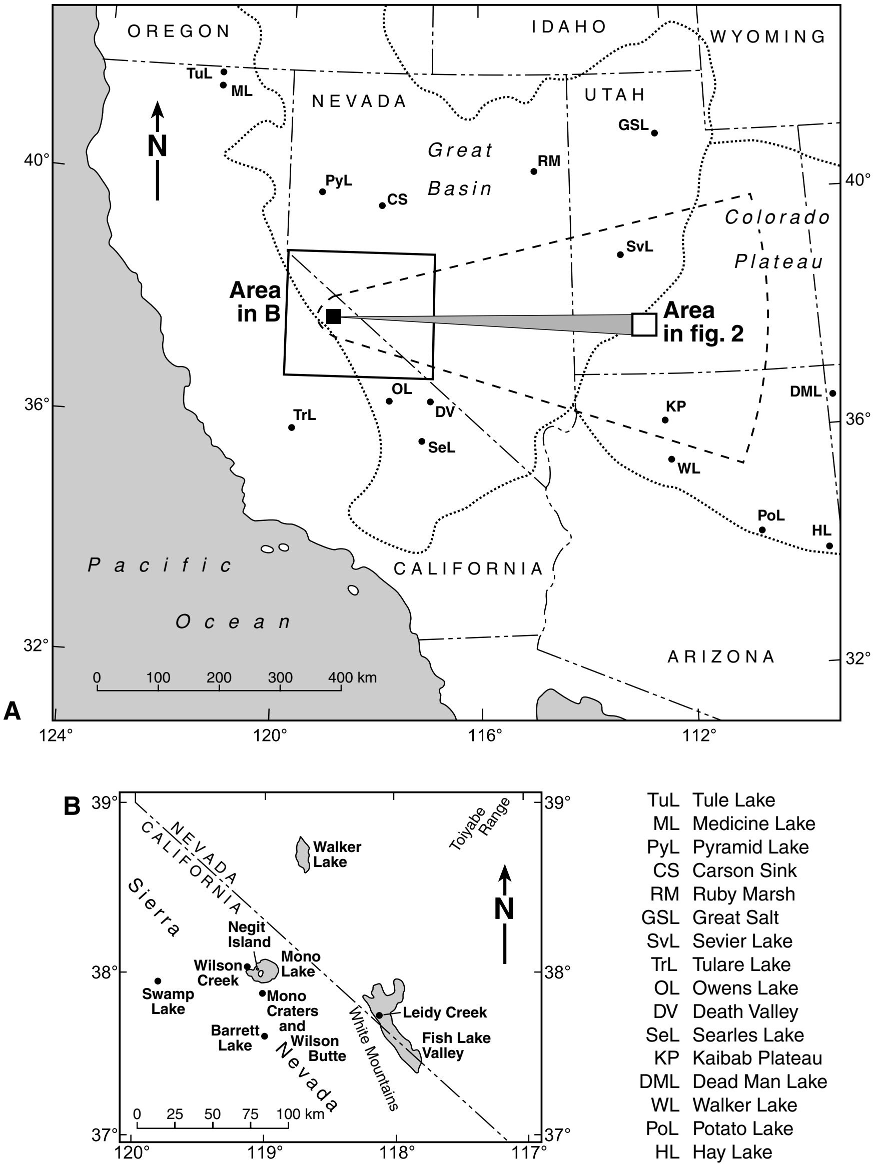

FIG. 1. Known (small gray wedge) and potential (large dashed wedge) distribution of the Lowder Creek ash in the western United States. Also shown are the locations of the study area (Fig. 2) and other places mentioned in the text. Dotted lines denote limits of the Great Basin and Colorado Plateau physiographic provinces.

tectosilicates (feldspar and quartz). Traces of etched hornblende are also present, as are diatoms of at least two species.

ANALYTICAL METHODS

Volcanic ash layers in core #1 were sampled, and volcanic glass shards from the layers were separated and analyzed, using methods described by Sarna-Wojcicki *et al.* (1984). Samples were wet-sieved with water in plastic sieves fitted with nylon screens that retained the 100 to 200 mesh size fraction (~80–~150 μm). In an ultrasonic vibrator this fraction was first washed with water, then treated with a 10% solution of HCl for a few minutes to remove authigenic carbonate adhering to the glass particles, and, finally, with an 8% solution of HF for about 30 s to 1 min, to remove other coatings or altered rinds that may have been present on the glass shards. The shards were then separated from other components of the tephra sample using a magnetic separator and heavy liquids of various densities made from mixtures of methylene iodide and acetone.

The glass separates were mounted in epoxy resin in shallow holes drilled into plexiglass slides, and the slides were ground down and polished with diamond paste to expose the shards and prepare a smooth, uniform surface for analysis. The polished sample was coated with carbon, and individual shards were analyzed by electron microprobe. Analytical conditions were those

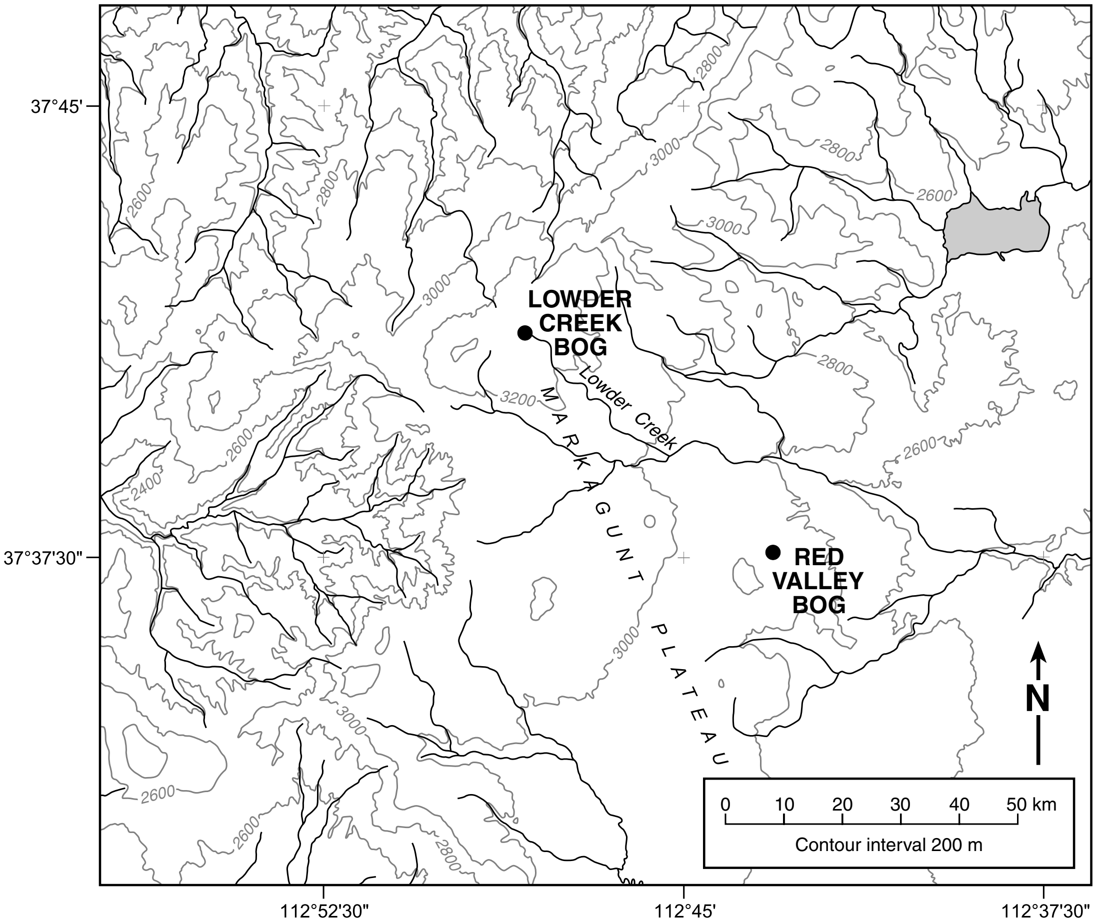

FIG. 2. Location of Lowder Creek and Red Valley bogs on the Markagunt Plateau, southwestern Utah.

described by Sarna-Wojcicki *et al.* (1984, 1985). Some of the tephra layers used for comparative purposes (Table 1) were analyzed previously by other instruments.

The polished glass shards were analyzed for Si, Al, Fe, Mg, Mn, Ca, Ti, Na, and K. Approximately 15 to 20 shards were analyzed from each of two samples. Results of analyses were compared with the U.S. Geological Survey tephrochronologic database, which describes approximately 4500 samples of volcanic glass from upper Neogene tephra layers in the conterminous western United States and from bottom sediments of the adjacent Pacific Ocean. The best matches were identified using numerical and statistical programs (SIMANAL; Sarna-Wojcicki *et al.*, 1984). The best matches were then examined for petrographic similarities and for stratigraphic position and sequence (Sarna-Wojcicki and Davis, 1991). Possibly correlative layers are identified on the basis of three main criteria: (1) chemical composition of volcanic glass, (2) petrographic characteristics of shards and mineralogy, and (3) stratigraphic position or related age. Comparisons of tephra layers for the purpose of correlation were made with several combinations of elements, excluding elements present in concentrations close to the detection limit.

CORRELATIONS

The volcanic glass shards from the ash layers in the cores are similar in composition to several ash layers erupted from the Mono Craters in east-central California. The Mono Craters comprise volcanoes, volcanic vents, explosion pits, and products of their eruptions aligned along an arc that extends southward about 17 km from the south shore of Mono Lake to Wilson Butte, east of the central Sierra Nevada. This volcanic field has produced multiple eruptions of rhyolitic lava, pumice, and ash (Lajoie, 1968; Bailey, 1989). Many of the eruptions have scattered ash over wide areas to the west in the high Sierra Nevada and its western foothills, to the north in the Carson Sink and Pyramid Lake areas, and as far east as the Toiyabe Range in central Nevada.

Stratigraphic sections containing multiple tephra layers from the Mono Craters are found near both the north and south shores of Mono Lake. At least 18 tephra layers dating to between ~36,000 and 13,000 ^{14}C yr B.P. have been documented at these sites (Lajoie, 1968). Tephra layers as old as ~50,000 ^{14}C yr B.P. were found on a causeway briefly exposed between the north shore and Negit Island of Mono Lake during a lake lowstand

TABLE 1

Results of Electron-Microprobe Analysis of Volcanic Glass Shards from Lowder Creek Bog, Utah, with Comparison to Several Ash Beds Erupted from the Mono Craters of East-Central California

	SiO_2	Al_2O_3	FeO	MgO	MnO	CaO	TiO_2	Na_2O	K_2O	Total
BH-DM-1 lower Lowder Creek Bog ash (19 shards)										
Average	72.822	12.156	0.920	0.031	0.040	0.570	0.054	3.343	4.395	94.330
±1 SD	0.474	0.186	0.068	0.008	0.024	0.024	0.040	0.207	0.157	0.731
Range	1.622	0.598	0.228	0.030	0.086	0.083	0.165	0.777	0.666	2.784
Low	71.942	11.798	0.809	0.013	0.012	0.521	0.000	2.922	4.145	92.752
High	73.564	12.396	1.037	0.043	0.098	0.604	0.165	3.699	4.811	95.536
BH-DM-2 upper Lowder Creek Bog ash (17 shards)										
Average	72.979	12.132	0.913	0.029	0.056	0.556	0.061	3.458	4.362	94.545
±1 SD	0.801	0.220	0.054	0.010	0.027	0.032	0.035	0.186	0.202	1.017
Range	3.584	0.893	0.195	0.034	0.089	0.140	0.109	0.681	0.851	3.784
Low	70.504	11.507	0.834	0.015	0.017	0.482	0.012	3.093	3.781	92.287
High	74.088	12.400	1.029	0.049	0.106	0.622	0.121	3.774	4.632	96.071
KRL7982-3 Wilson Creek ash 3										
Average	74.282	12.536	0.916	0.013	0.034	0.58	0.040	3.904	4.508	95.949
±1 SD	0.520	0.226	0.053	0.004	0.027	0.045	0.013	0.116	0.180	n.d.
KRL7982L Wilson Creek ash 4 (lower)										
Average	72.212	12.069	0.925	0.025	0.041	0.590	0.032	3.663	4.196	93.753
±1 SD	0.470	0.280	0.065	0.010	0.031	0.067	0.013	0.139	0.170	n.d.
KRL7982U Wilson Creek ash 4 (upper)										
Average	74.468	12.548	0.926	0.019	0.046	0.573	0.033	3.814	4.401	96.828
±1 SD	0.557	0.239	0.058	0.007	0.027	0.053	0.017	0.085	0.142	n.d.
Samples Recalculated to 100%										
BH-DM-1										
Recalculated	77.200	12.887	0.975	0.033	0.042	0.604	0.057	3.544	4.659	100.00
BH-DM-2										
Recalculated	77.190	12.832	0.966	0.031	0.059	0.591	0.065	3.658	4.614	100.00
Similarity coefficient (5 oxides)	1.000	0.996	0.991	[0.909]	[0.711]	0.978	[0.877]	[0.969]	0.99	0.991
KRL7982-3										
Recalculated	77.418	13.065	0.955	0.014	0.035	0.604	0.042	4.069	4.698	100.00
Similarity coefficient (5 oxides)	0.997	0.986	0.979	[0.424]	[0.712]	1.000	[0.737]	[0.877]	0.992	0.991
KRL7982-4L										
Recalculated	77.024	12.873	0.987	0.027	0.043	0.629	0.034	3.907	4.476	100.00
Similarity coefficient (5 oxides)	0.998	0.999	0.987	[0.818]	[0.977]	0.960	[0.596]	[0.907]	0.961	0.981
KRL7982-4U										
Recalculated	76.908	12.959	0.956	0.020	0.048	0.592	0.034	3.939	4.545	100.00
Similarity coefficient(5 oxides)	0.996	0.994	0.981	[0.606]	[0.875]	0.960	[0.596]	[0.899]	0.996	0.981
SL-673										
Recalculated	76.860	12.99	0.973	0.030	0.05	0.610	0.050	3.700	4.750	100.01
Similarity coefficient (5 oxides)	0.995	0.992	0.998	[0.909]	[0.840]	0.990	[0.877]	[0.958]	0.981	0.985
FLV-145A-VS										
Recalculated	76.940	13.11	0.946	0.030	0.04	0.600	0.070	3.700	4.550	99.99
Similarity coefficient (5 oxides)	0.997	0.983	0.970	[0.909]	[0.952]	0.993	[0.814]	[.958]	0.977	0.984

Note. Data obtained on analysis are given for samples 1–5. These are recalculated to a fluid-free basis (100%), in 1A–5A. The similarity coefficient is calculated between lower (primary ash fall) Lowder Creek Bog ash (1A) and the remaining samples (2A–5A). A similarity coefficient of 1.000 represents a perfect match (Sarna-Wojcicki *et al*., 1984). Matches with two other tephra layers, derived from the Mono Craters source but found at more distal sites, are also presented (6A, from Swamp Lake, Sierra Nevada, CA; and 7A, from Fish Lake Valley, CA/NV). C. E. Meyer and J. P. Walker, analysts, U.S. Geological Survey, Menlo Park, CA, 1978–1999.

in the 1980s and in cores taken from Walker Lake, Nevada (Sarna-Wojcicki *et al*., 1988). Activity at the Mono Craters continued throughout most of Holocene time. K. R. Lajoie (unpublished data, 1979) described approximately 10 tephra layers in the range 11,100 to 1000 ^{14}C yr B.P. Additional late Holocene tephra layers, presumed to have been derived from the northernmost Panum Crater and a nearby explosion pit, have been correlated to layers dated variously from ~850 to ~550 ^{14}C yr B.P. (Wood, 1977; Sieh and Bursik, 1986).

At least 35 major tephra layers erupted from Mono Craters during the last ~50,000 ^{14}C yr. Distinction among these units is made difficult by chemical and petrographic similarities. Closest matches to the Lowder Creek tephra are ash beds #3 and #4 in the uppermost tephra layers exposed in the Wilson Creek beds north of Mono Lake (Table 1, KRL-7982-3, KRL-7982-4L/KRL-7982-4U). Other close matches are to a tephra layer at 6.73 m in the Swamp Lake core (Table 1, SL-673), Sierra Nevada (Smith, 1990), and to a tephra layer in Fish Lake Valley, east of the White Mountains along the California/Nevada border (Table 1, FLV-145A-VS) (Reheis *et al*., 1995, 1996).

The composition of the Lowder Creek shards matches that of Wilson Creek ash beds #3 and #4, except for the oxides that are close to the detection limit (MgO, MnO, and TiO_2). For these oxides a natural scatter exists due to larger analytical errors. Large differences are also present, however, for sodium. Sensitive to variations in analytical technique and instrumentation, sodium content can vary from one set of analyses to the next, even with the same instrument, analyst, and standards (Smith and Westgate, 1969; Sarna-Wojcicki *et al*., 1984). Furthermore, sodium tends to be highly mobile in the natural depositional and storage environment, commonly becoming either enriched or depleted, depending on the geochemical environment (Cerling *et al*., 1985; Sarna-Wojcicki and Davis, 1991). For these reasons, we discount variations in sodium when making correlations on the basis of glass composition. To investigate instrument variation, we compared analyses that were run in 1982 on an Applied Research Laboratories instrument (KRL-7982-3 and KRL-7982-4) with analyses that were run in 1999 on a JEOL-8900 instrument. Despite close similarities in most of the oxides, a disparity in sodium exists for these analyses (Table 2). We

TABLE 2

Samples from Lowder Creek Bog (BH-DM-1 and BH-DM-2), Wilson Creek Ash #3 (KRL7982-3), and Wilson Creek Ash #4 (KRL7982-4U and KRL7982-4L) Reanalyzed to Detect Sodium Variability

	Na_2O	MgO	Al_2O^3	SiO_2	K_2O	CaO	TiO_2	MnO	FeO	Total
					BH-DM-1 T372-1					
Average	3.723	0.029	12.207	72.885	4.383	0.567	0.048	0.051	0.869	94.764
±1 SD	0.127	0.008	0.190	1.068	0.071	0.033	0.029	0.036	0.050	1.337
Count	20	20	20	20	20	20	20	20	20	20
					BH-DM-2 T372-2					
Average	3.729	0.031	12.233	73.134	4.382	0.552	0.048	0.035	0.867	95.013
± SD	0.099	0.008	0.170	0.517	0.079	0.025	0.028	0.029	0.063	0.738
Count	19	19	19	19	19	19	19	19	19	19
					KRL7982-3 T44-4					
Average	3.824	0.019	12.602	73.804	4.518	0.554	0.038	0.053	0.836	96.248
±1 SD	0.186	0.008	0.252	0.789	0.079	0.030	0.024	0.028	0.077	0.871
Count	21	21	21	21	21	21	21	21	21	21
					KRL7982-4U T49-5					
Average	3.786	0.016	12.462	73.144	4.361	0.558	0.038	0.040	0.798	95.203
±1 SD	0.158	0.008	0.254	0.902	0.098	0.029	0.029	0.027	0.069	1.195
Count	19	19	19	19	19	19	19	19	19	19
					KRL7982-4L T49-4					
Average	3.697	0.012	12.251	72.418	4.218	0.533	0.042	0.041	0.749	93.961
±1 SD	0.085	0.005	0.146	0.482	0.062	0.036	0.024	0.028	0.073	0.598
Count	20	20	20	20	20	20	20	20	20	20
					BH samples recalculated to 100%					
BH-DM-1	3.92	0.03	12.87	76.83	4.62	0.60	0.05	0.05	1.02	99.99
BH-DM-2	3.92	0.03	12.86	76.89	4.61	0.58	0.05	0.04	1.01	99.99
					KRL samples recalculated to 100%					
KRL-7982-3	3.97	0.02	13.08	76.61	4.69	0.58	0.04	0.06	0.96	100.01
KRL-7982-4U	3.97	0.02	13.08	76.76	4.58	0.59	0.04	0.04	0.93	100.01
KRL-7982-4L	3.93	0.01	13.03	77.00	4.49	0.57	0.04	0.04	0.88	99.99

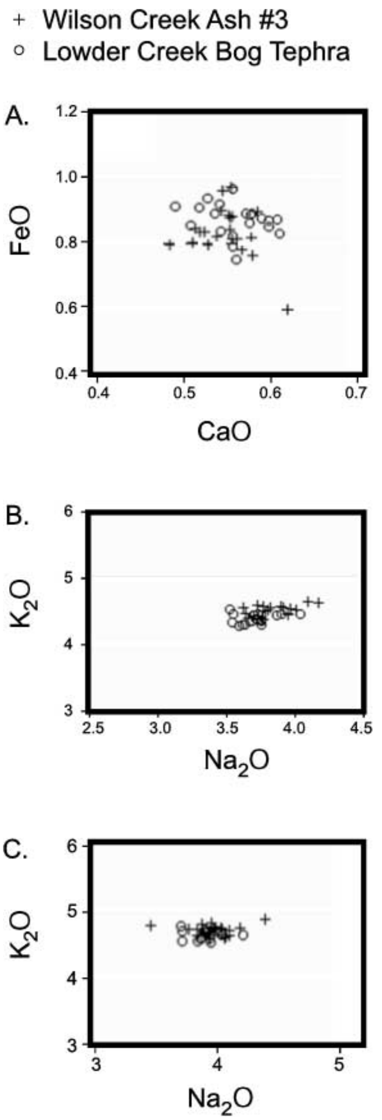

FIG. 3. Scatter plots for samples BH-DM-1, the Lowder Creek bog tephra layer (○), and KRL7982-3, Wilson Creek ash bed #3 (+), reanalyzed on the same instrument to check for consistency in sodium concentrations: (A) CaO versus FeO, (B) Na_2O versus K_2O, plot unnormalized for hydration, and (C) Na_2O versus K_2O; plot normalized for hydration (see text). Note that the slight offset in the Na_2O versus K_2O plot in B is not present in C. The more efficient hydration of the smaller, distal glass shards at Lowder Creek bog probably accounts for the difference in Na_2O and K_2O in plot B.

therefore reanalyzed the samples and found an improved overall match between the Lowder Creek ash bed and Wilson Creek ash beds, particularly for the troublesome sodium values (Fig. 3).

Aside from the late Pleistocene ash beds that erupted from the Mono Craters and crop out on the north and south shores of Mono Lake, no volcanic sources in the western conterminous U.S. have exactly the combination of oxides in the Lowder Creek bed. The Medicine Lake area, northeastern California has somewhat similar silicic domes, and tephra of comparable composition is present in the nearby Tule Lake. Compared with the Mono Craters ash, this type of tephra has higher MgO and TiO_2, a much greater age (between about 400,000 and 600,000 yr B.P.), and no known examples far from the source area. All other tephra sources known to us, within the age range of modern (Mount St. Helens) to middle Miocene, have different compositions. For example, tephra derived from sources in the Cascade Range has significantly higher FeO, MgO, MnO, TiO_2, and CaO. Tephra derived from the El Cajete source in the Jemez Mountains, on the other hand, is not only different in composition, but the eruptive ages are also too old to correlate with the Lowder Creek tephra. The tephra layer thus correlates with the younger Wilson Creek ash beds erupted from the Mono Craters of east-central California, but these resemble one another too much for a more specific match without additional analyses.

AGE

The age of the Lowder Creek ash layer in the cores taken by Mulvey *et al.* (1984) is loosely limited by radiocarbon dates of 14,400 ± 850 ^{14}C yr B.P. (UCR-1661) and 9570 ± 480 ^{14}C yr B.P. (Beta-5744) measured on bulk organic mud 0.7 m below and 0.1 m above the ash layer. The bog was also cored to a depth of 7.23 m by Anderson *et al.* (1999). They obtained dates of 13,020 ± 690 ^{14}C yr B.P. (Beta-56945) and 9200 ± 100 ^{14}C yr B.P. (Beta-59897) on bulk sediment samples collected from ranges of 7.04–7.21 m and 5.00–5.12 m below the surface. Although the ash was not noted, these dates may also bracket the time of ash fall. The age of the Lowder Creek tephra may be further limited by the depositional sequence at the nearby Red Valley bog (Fig. 2), where $^{13}C/^{12}C$-corrected basal dates are 11,795 ± 90 (WW-2355) and 11,645 ± 95 (WW-2354)^{14}C yr B.P. Because the tephra is not present in this bog, its fall may predate 12,000 ^{14}C yr B.P.

We attempted to limit the age of the tephra more closely by dating pollen from silty clay bracketing the 2-mm-thick air-fall tephra layer. After carefully cleaning the exterior of core #1, we cut 5-mm-thick samples from immediately above and below the ash. We then used a simplified version of the preparation technique devised by Brown *et al.* (1989) to concentrate fossil pollen for accelerator mass spectroscopy (AMS) radiocarbon dating. Sediment samples were sieved, treated with hydrochloric and hydrofluoric acids, and KOH was then used to remove portions of the nonpollen organic materials. The final residues, although not pure pollen concentrates, were predominately composed of pollen grains.

This simplified procedure has been used in ongoing research at Great Salt Lake (Thompson and Oviatt, 1999; unpublished data), where the pollen AMS dates from sediments surrounding the Mazama ash (∼6800 ^{14}C yr B.P.) have been found to be as much as 700 ^{14}C yr too old. The sample preparation technique improves the accuracy of the radiocarbon ages, as bulk organics from the same horizons are as much as 1700 ^{14}C yr (or more) too old. Mensing and Southon (1999) used a manual separation technique to produce essentially pure concentrations of fossil pollen for AMS dating. They evaluated the accuracy of the

TABLE 3
Radiocarbon Age Estimates of Samples from Lowder Creek Bog

Height (cm)[a]	Material	Age (^{14}C yr B.P.)	Age (cal yr B.P.)	Laboratory no.
219–231[b]	bulk organic	9200 ± 100	10,190–10,670	Beta-56945
137	plant material	10,950 ± 90	12,660–13,160	WW-2351
134	wood	10,910 ± 40	12,660–13,140	WW-2238
132	pollen	11,835 ± 90	13,480–14,090	WW-2352
102[b]	bulk organic	9570 ± 480	9600–12,600	Beta-5744
89	pollen	14,260 ± 60	16,620–17,590	WW-1775
88	tephra			
87	pollen	14,280 ± 60	16,640–17,610	WW-1776
50	pollen	14,620 ± 110	16,990–18,090	WW-2358
30–47[b]	bulk organic	13,020 ± 690	13,550–17,230	Beta-56945
33[b]	bulk organic	14,400 ± 850	14,460–19,370	UCR-1661
19	pollen	16,930 ± 70	19,540–20,800	WW-2064
3	pollen	17,400 ± 160	20,000–21,420	WW-2353

[a] Relative to the clean sand and gravel at base of the lacustrine deposits.

[b] Approximate position of age estimates from Mulvey *et al.* (1984) and Anderson *et al.* (1999) relative to the base of the lacustrine deposits; calibrated calendar ages derived using Calib 4.3 and showing maximum and minimum age of all intercepts at 2 σ.

resultant AMS dates by dating sediments adjacent to the Mazama ash from lakes in the Sierra Nevada. Although many of their dates were equivalent to the known age of the Mazama ash, a few were as much as 300 ^{14}C yr too old. This suggests that even the purest pollen concentrates may contain materials hundreds of years older than the time of deposition.

The pair of Lowder Creek pollen separates from core #1 bracketing the tephra produced ages that scarcely differ from one another. The 5-mm sample below the ash dates to 14,280 ± 60 ^{14}C yr B.P. (WW-1776), while that above the ash dates to 14,260 ± 60 ^{14}C yr B.P. (WW-1775). To check the possibility that these age estimates are older than surrounding sediment, we obtained six additional ages from lacustrine clay in the lowest 1.37 m of a second core collected in 1998. Altogether, 12 age estimates, including four obtained by Mulvey *et al.* (1984) and Anderson *et al.* (1999), are useful in interpreting the age of the tephra (Table 3, Fig. 4).

The six pollen dates from the two cores are stratigraphically consistent in terms of age and stratigraphic position but appear somewhat older than age estimates based on other materials. For example, a fragment of wood and unidentified plant material from 46 and 49 cm above the tephra date to 10,910 ± 40 (WW-2238) and 10,950 ± 90 (WW-2351) ^{14}C yr B.P., respectively, while a pollen sample 44 cm above the ash, immediately below the wood, dates to 11,835 ± 90 (WW-2352) ^{14}C yr B.P. Pollen separates from 69 and 85 cm below the ash date to 16,930 ± 70 (WW-2064) and 17,400 ± 160 (WW-2353), respectively. Ages on bulk organics obtained by Mulvey *et al.* (1984) and Anderson *et al.* (1999), from depths between these lower samples and those bracketing the ash, are somewhat younger than ages interpolated from the pollen samples. Because these bulk-organic ages have large standard deviations and come from cores that did not reach the basal sandy gravel, they cannot be directly correlated with the sequence from our core #1. However, the dates are generally consistent with those we obtained. We are therefore confident that the average age of ~14,300 ^{14}C yr B.P. for the two dates

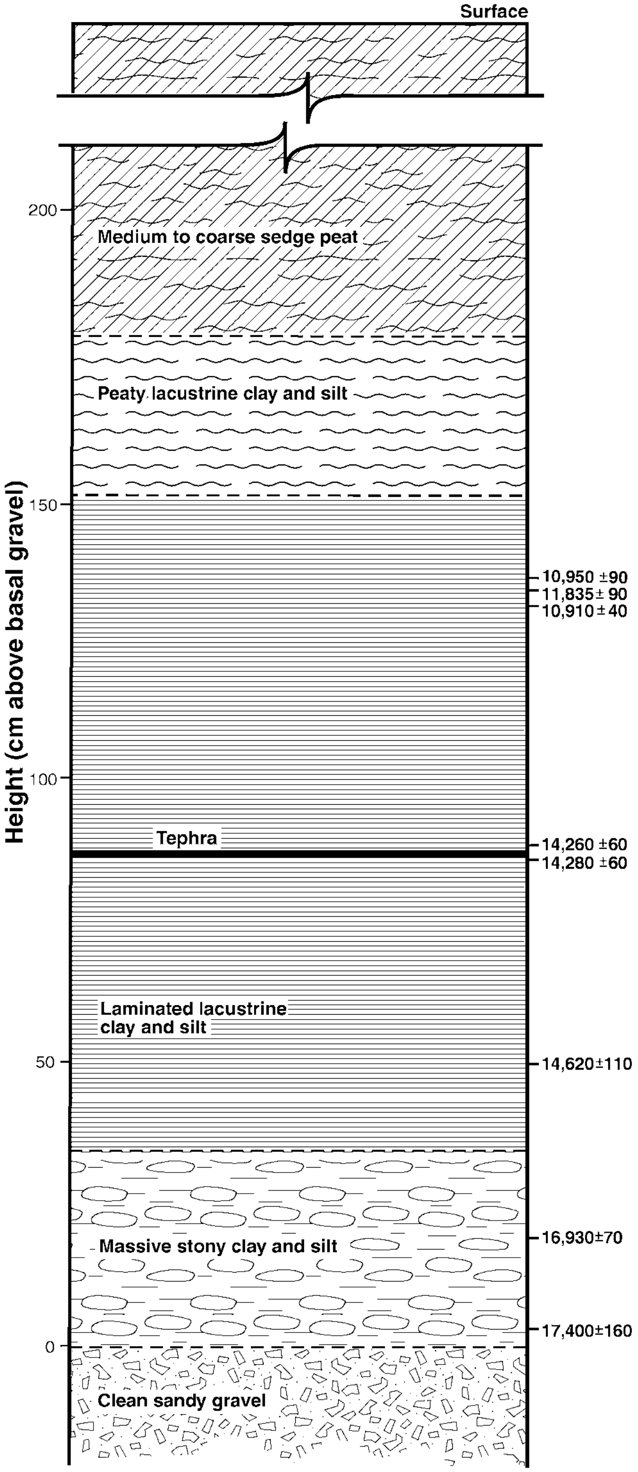

FIG. 4. Schematic representation of radiocarbon age estimates bracketing the Lowder Creek ash in the Lowder Creek bog stratigraphic sequence.

bracketing the ash is close to the true age of the ash fall event but hold out the possibility the eruption may be slightly younger.

The chemical composition of the volcanic glass strongly suggests that the Lowder Creek tephra correlates with Wilson Creek ash bed #3 or, less likely, #4. The ages of these ash beds are interpolated to be 14,260 and 14,760 ^{14}C yr B.P., respectively, based on a sequence of radiocarbon dates on tufa and ostracode valves in the Wilson Creek section (Lajoie, 1968; Benson *et al.*, 1990). A regression of stratigraphic position versus ^{14}C age on multiple dates in the section by K. R. Lajoie (unpublished data) provides the above age estimates. The volcanic ash from Swamp Lake, California (Table 1, SL-673), is interpolated to have fallen $\sim$12,545 ^{14}C yr B.P. (Smith, 1990). This age is based on bulk peat dates of 13,690 ± 340 and 10,420 ± 100 ^{14}C yr B.P. collected at depths of 7.06–7.16 m and 6.00–6.10 m from the same core. However, because the Tsoyowata ash bed, dated to 7015 ± 45 ^{14}C yr B.P. (Bacon, 1983), occurs at a depth of 4.29 m in the same core, changes in deposition rates may complicate interpolation.

In approximate age, the Lowder Creek ash also resembles Mono Craters tephras found in Fish Lake Valley. A core from the Leidy Creek fan contains tephras (Table 1, FLV-145A-VS) estimated to be about 13,000 ^{14}C yr B.P., below peat dated to 11,736 ± 150 ^{14}C yr B.P. (Reheis *et al.*, 1995, 1996). Volcanic ash horizons dated to the early Holocene, such as that at Barrett Lake, California (Anderson, 1990), may also be from the same eruption if their dating is spurious. For the moment, we consider the age of the Lowder Creek tephra to be $\sim$14,000 ^{14}C yr B.P.; more dating is needed to test this age and the inferred correlations with tephra at other sites.

DISTRIBUTION

The distribution of all previously known Mono Craters tephra layers is limited to areas within 250 km of the crater chain on the western edge of the Great Basin (Fig. 4). Because Lowder Creek bog is $\sim$550 km east of Mono Craters on the Colorado Plateau near the eastern margin of the Great Basin, the late Pleistocene eruptive event that produced the ash was probably much larger than any of the subsequent Holocene eruptions. Except for the locations noted above, tephra layers similar to the Lowder Creek ash have not yet been recovered from any other sites in California, Nevada, Utah, or Arizona.

The apparent absence of the Lowder Creek tephra from the Carson Sink and Pyramid Lake areas, where the late Jonathan O. Davis made extensive stratigraphic and tephrochronological studies (e.g., Davis, 1978), suggests that the ash was not deposited in this region or that depositional conditions were not favorable to its preservation. The plume may have also failed to reach the northern Bonneville basin, where it is unknown from outcrop surveys (Currey, 1990; Oviatt *et al.*, 1992) and from cores in the southern arm of Great Salt Lake (Spencer *et al.*, 1984; Thompson and Oviatt, 1999). To the north, the ash is unknown from Walker Lake, Nevada (Bradbury *et al.*, 1989); Ruby Marsh, Nevada (Thompson, 1992); and Sevier Lake, Utah (Thompson *et al.*, 1995); but apparent hiatuses in sediment accumulation for the period of the deposition corresponding to the Lowder Creek tephra may account for this absence.

The southern margin of the ash fall may be limited by records from Tulare Lake, California (Davis, 1999); Death Valley, California (Lowenstein *et al.*, 1999); Searles Lake, California (Litwin *et al.*, 1999); Owens Lake, California (Smith and Bischoff, 1997); the Kaibab Plateau, Arizona (Weng and Jackson, 1999); Walker Lake, Arizona (e.g., Hevly, 1985); Potato Lake, Arizona (Anderson, 1993); Dead Man Lake, New Mexico (Wright *et al.*, 1973); and Hay Lake, Arizona (Jacobs, 1985). Unfortunately, problems with many of these records, including poor recovery in this part of the section (e.g., Owens Lake), depositional hiatuses (e.g., Tulare, Walker, and Potato Lakes), and insufficient age (e.g., the Kaibab Plateau), make it difficult to estimate southern limits.

Wind direction may have been from directly west to east during the time of ash fall, for Lowder Creek bog (37°40′N) is almost due east of Mono Craters (37°48′–56′N). However, it is also possible that Lowder Creek bog was at the southern or northern margin of the ash plume. A plausible ash-fall area extends from central Utah to northern Arizona (Fig. 1). Given the 2 mm of clean air-fall ash in the Lowder Creek bog sequence, at a location more than 500 km from the volcanic vent, the area covered by the Lowder Creek ash likely extends well to the east. How far east is uncertain, but the plume may have deposited tephra well onto the Colorado Plateau.

CONCLUSIONS

Identification and dating of a volcanic ash from Lowder Creek bog suggest the Lowder Creek tephra may serve as a chronostratigraphic marker bed linking late Pleistocene deposits across much of the southern Great Basin and west-central Colorado Plateau. The tephra was probably derived from a Mono Craters source area during an eruptive event dating to about 14,000 ^{14}C yr B.P. At Lowder Creek bog, the ash-fall event is dated to $\sim$14,300 ^{14}C yr B.P. Wilson Creek ash #3 is the best chemical match to the Lowder Creek ash and has a similar interpolated age (Lajoie, 1968).

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