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A STRATIGRAPHIC MARKER IN LAKE BONNEVILLE SEDIMENTS, UTAH

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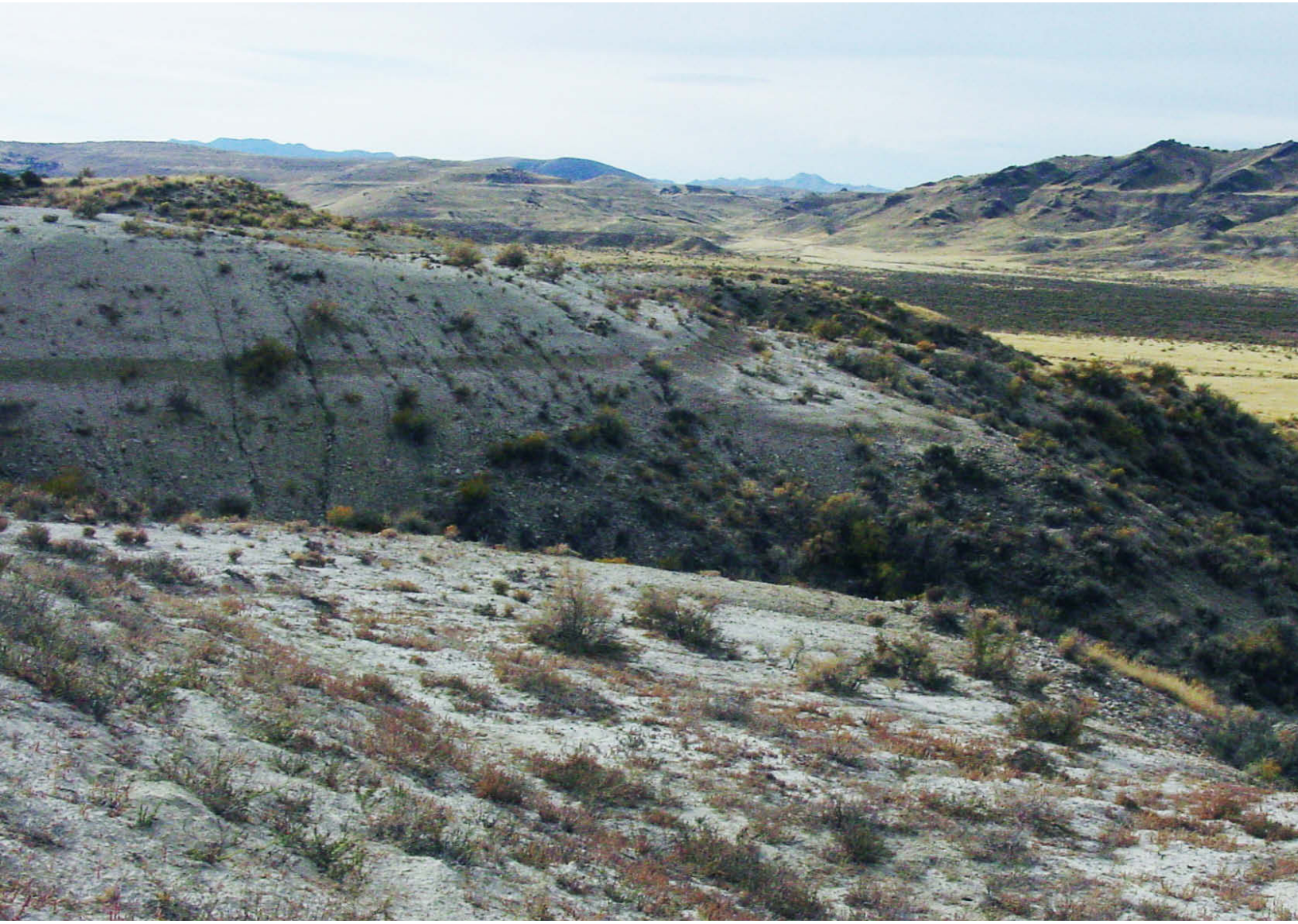

MISCELLANEOUS PUBLICATION 14-1
UTAH GEOLOGICAL SURVEY
a division of
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THE PONY EXPRESS BASALTIC ASH

A STRATIGRAPHIC MARKER IN LAKE BONNEVILLE SEDIMENTS, UTAH

by Charles G. Oviatt[1] and Barbara P. Nash[2]

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ISBN 978-1-55791-890-1

Cover photo: Exposure of Lake Bonneville sediments containing the Pony Express basaltic ash, adjacent to the Old River Bed southeast of where the Pony Express road crosses the Old River Bed. The ash (not visible from a distance) is at the base of the fine-grained lake sediments, a few centimeters above the gravel. View to the southwest. Photo by Susan Oviatt.

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ABSTRACT

The Pony Express basaltic ash was erupted from a vent in the Sevier Desert basin soon after Lake Bonneville had transgressed high enough to flood into the basin, but before it reached its highest altitude. The eruption occurred after the Stansbury oscillation and the formation of the Stansbury shoreline in the Great Salt Lake basin. The Pony Express ash is found at or near the base of the Bonneville marl below altitudes of 1400 m (4600 ft) in part of the Sevier Desert basin and the southernmost part of the Great Salt Lake basin. The chemical composition of the Pony Express ash is similar to that of other basalts in the Sevier Desert, particularly those in the Pahvant Butte area. Possible source vents are in the Pahvant Butte area, or a maar near Smelter Knolls. Radiocarbon ages of gastropods associated with the base of the Bonneville marl in the Sevier Desert basin indicate an age for the Pony Express ash of about 20,000 ^{14}C yr B.P. (~24,000 calibrated [cal] yr B.P.). The Pony Express ash is compositionally distinct from three other basaltic ashes found in Lake Bonneville deposits based on electron microprobe analysis of glass shards. A unique characteristic of the Pony Express ash is elevated levels of Cl that indicate interaction of the Pony Express magma with halite or Cl-rich brines during the phreatomagmatic eruption.

KEYWORDS

Pony Express ash; Lake Bonneville; Bonneville marl; Sevier Desert basin; Black Rock Desert; Utah; radiocarbon age; tephra; ash; volcanic glass; basalt; electron microprobe.

INTRODUCTION AND BACKGROUND

Basaltic tephras are not common in the stratigraphic record because basaltic volcanic eruptions generally are not explosive enough to produce ash that is widely distributed. Exceptions to this are ashes from hydrovolcanic eruptions that involve groundwater or surface water (Wohletz and Sheridan, 1983). Three basaltic volcanic ashes that are useful as stratigraphic correlation tools in the Bonneville basin are the Hansel Valley ash (referred to in earlier publications as the "Thiokol" ash; Oviatt and Nash, 1989; Oviatt and others, 1992; Miller and others, 1995, 2008), the Pahvant Butte ash (Oviatt and Nash, 1989), and the Tabernacle Hill ash (Oviatt and Nash, 1989) (figure 1). A fourth basaltic ash has been found in the Bonneville marl at one locality in the Sevier Desert, about 1 km (0.6 mi) northwest of Sevier Lake. This ash was informally referred to as the "Sevier Lake" ash by Nash (1991, figure 15). Stratigraphic relationships in a measured section of Lake Bonneville marl suggest the age of the "Sevier Lake" ash to be approximately 21,000 cal yr B.P., although its source and distribution have not been determined (the glass composition suggests it is not a Sevier Desert ash). In this report we describe a fifth basaltic ash, the Pony Express ash, which has been previously named in the literature (Oviatt and others, 1994a, 1994b; Oviatt, 1997), but has not had a full description of its age, stratigraphic relationships, or chemical composition. The Pony Express ash is typically identified in outcrops as a band of dark grains ranging in thickness from <1 mm to several mm (<0.04 to ~0.1 in.).

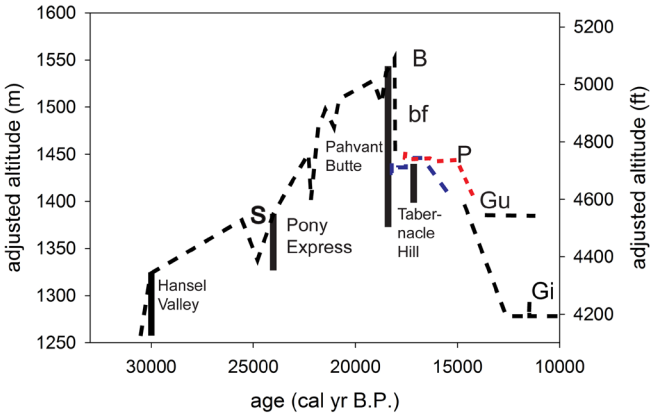

Figure 1. *Schematic diagram showing changes in lake level in Lake Bonneville (dashed line) and approximate ages and altitude limits of the four well-documented basaltic ashes in Lake Bonneville sediments. Lake-level chronology based on Oviatt and others (1992), Oviatt (1997), Godsey and others (2011), Miller and others (2012), and Reheis and others (in review). S = Stansbury shoreline zone; B = Bonneville shoreline; P = Provo shoreline; Gu = Gunnison shoreline (Sevier Desert basin); Gi = Gilbert shoreline (Great Salt Lake basin); bf = Bonneville flood. The two alternatives for Provo-shoreline chronology (short red-dashed line and blue long-dashed line) are from Miller and others (2012). Altitudes adjusted for the effects of differential isostatic rebound using the Currey equation (Oviatt and others, 1992). Ages are given in calibrated years before present. The basaltic ashes in the Bonneville basin (except for the Sevier Lake ash, which is not well dated and is only found at one locality) are shown by black lines that show the altitudinal limits of known outcrops of each ash.*

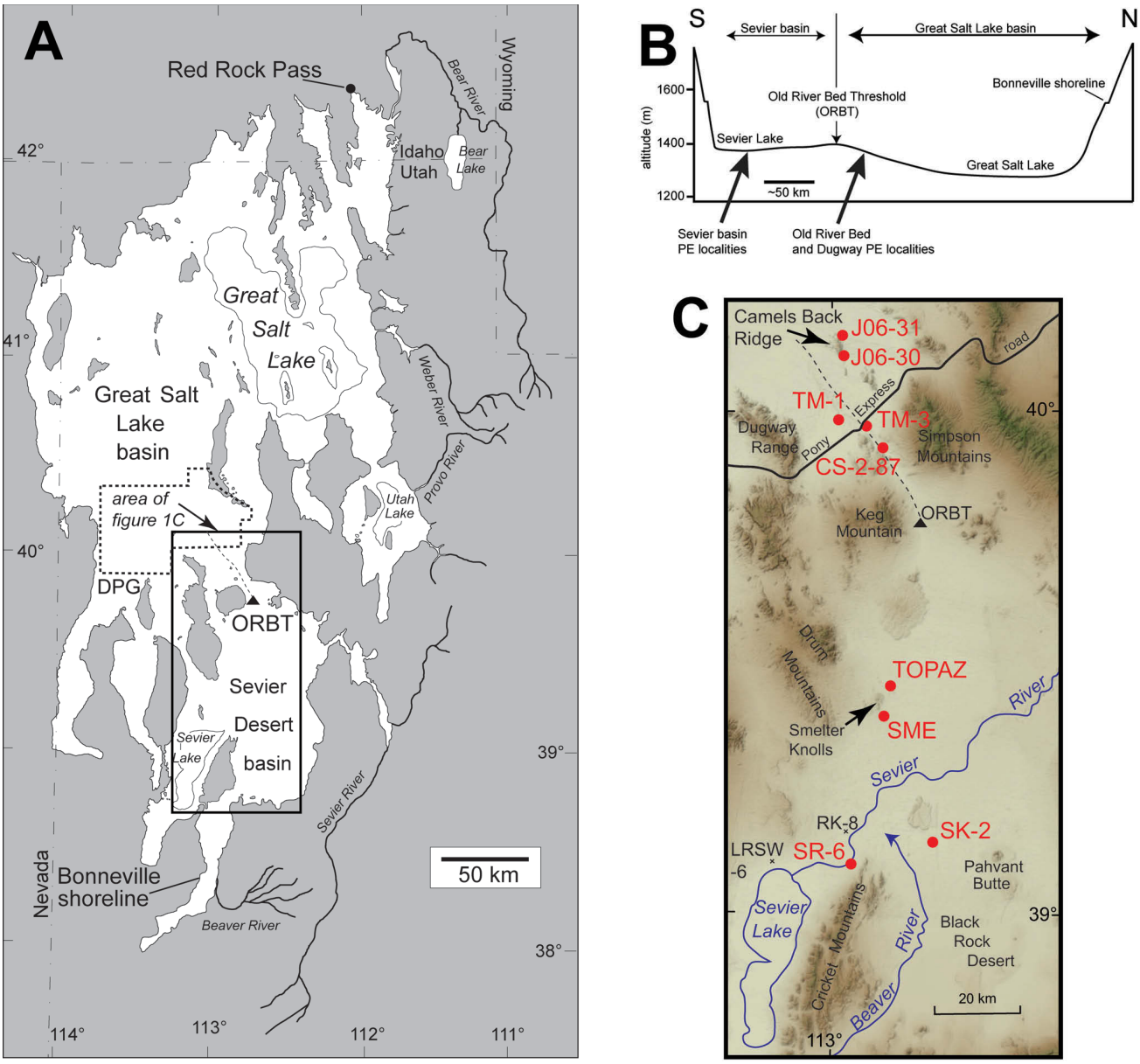

Figure 2. *(A) Map of the maximum extent of Lake Bonneville in western Utah, eastern Nevada, and southern Idaho. ORBT = Old River Bed threshold, the topographic divide between the Sevier Desert and Great Salt Lake basins; fine dashed line is the Old River Bed. Red Rock Pass is the post-flood overflow point of Lake Bonneville at the Provo shoreline. DPG = Dugway Proving Ground, boundary marked as dotted line. (B) Schematic north-south topographic profile across the Sevier Desert basin and the Great Salt Lake basin, showing the shallow Sevier Desert basin and the ORBT. (C) Enlarged shaded-relief map of part of map 2A showing localities where Pony Express ash has been found; see table 1 for location coordinates. Localities LRSW-6 and RK-8 are mentioned in the text. Fine dashed line is the Old River Bed.*

Although the eruptive vent that produced the Pony Express ash has not been identified, the distribution of the ash and its chemical signature indicate that it came from a source somewhere in the Sevier Desert basin (figure 2). In the Sevier Desert basin the ash is found at or near the base of the fine-grained offshore or deep-water sediments (the "white marl") of Lake Bonneville, on or near the floor of the basin, and therefore it was erupted at about the time Lake Bonneville had transgressed high enough to flood into the Sevier Desert, at about 24,000 cal yr B.P., after the Stansbury oscillation and formation of the Stansbury shoreline in the Great Salt Lake basin (figure 1). The ash has been found at localities as much as 45 km (30 mi) north of the topographic divide between the Sevier Desert basin and the Great Salt Lake basin (the Old River Bed threshold [ORBT]; figure 2), but it is not present in cores of Lake Bonneville sediments from the floor of the Great Salt Lake.

The name "Pony Express" is taken from the place where the Pony Express road crosses the exposures of Lake Bonneville sediments along the bluffs of the Old River Bed (ORB) in Tooele County, Utah (figure 2). The Pony Express ash is near the base of the Bonneville marl in these badland exposures (locality TM-3; figures 2, 3, and 4). G.K. Gilbert (1890)

first described the stratigraphic section in this area, but did not note the Pony Express ash. Varnes and Van Horn (1961) did not mention the Pony Express ash in their publications, but spotted it in the field, and referred to it informally as the "honey-colored ash" (D. Varnes and R. Van Horn, personal communication to Oviatt, about 1990).

Oviatt (1987) measured stratigraphic sections along the ORB but did not mention the Pony Express ash. Later the ash was collected by Oviatt and geochemical data were provided by Nash in a Utah Geological Survey publication (Oviatt and others, 1994b), and it was described in sediment cores taken near TM-3 (Oviatt and others, 1994a; Oviatt, 1997). The Pony Express ash was found in a sediment core taken near Sunstone Knoll in the Sevier Desert (Oviatt and others, 1994a), and Nash analyzed the composition of the glass in a sample of that occurrence of the ash, although the data were not published. We have found the Pony Express ash at several other places, both north and south of the ORBT (figure 2; table 1).

A possible source vent for the Pony Express ash is the maar at the southern end of Smelter Knolls in the Sevier Desert (table 1; figures 2C and 5). This maar is well preserved as a landform because its rim consists of erosion-resistant basalt (the basalt flow was dated to about 300,000 yr by Turley and Nash, 1980, using the potassium-argon method, but the maar could be much younger). The Smelter Knolls maar has an altitude of about 1420 m (4660 ft), so it is low in the basin, but high enough to have produced a tuff ring that would have been destroyed as Lake Bonneville transgressed across this altitude soon after the eruption. Several attempts in the field to find glassy tephra near the maar have failed, but granule and coarse-sand basalt fragments are abundant at the base of Bonneville sediments where they are exposed in stream cuts and gravel pits near the maar. A section of Bonneville sediments that was exposed in the 1980s and 1990s in a gravel pit about 6 km northeast of the Smelter Knolls maar included two beds of "sand with basalt granules" at the base of the section (table 1; Light, 1993, figure 24). This section is no longer exposed (as of May 2012) because of the development of a landfill at the site, but Light's (1993) description is similar to that of other Bonneville exposures nearby. If the Smelter Knolls maar was the source vent for the Pony Express ash, Lake Bonneville would have dispersed the fine-grained and low-density glass and pumice fragments, then rounded and reworked the denser fragments of comminuted bedrock basalt into beach deposits. Phreatomagmatic eruptions that

Table 1. *Pony Express ash localities.*

Locality[1]	Quadrangle	Latitude ° N[2]	Longitude ° W[2]	Altitude (ft)	Altitude (m)	Adj alt[3] (m)	Notes	cm above base[4]	Reference
SK-2	Sunstone Knoll	39.147	112.710	4570	1390	1380	basaltic ash grains mixed with marl; found in a sediment core near the base of the marl	0-15	Oviatt and others, 1994a
SR-6	Red Pass	39.117	112.928	4540	1385	1375	basaltic ash grains mixed with massive marl beneath laminated marl at the base of the section	0	this paper
CS-2-87	Coyote Springs	39.928	112.853	4530	1380	1360	very thin (<1 mm) double lamination of basaltic ash	2	this paper
TM-1	Table Mountain	39.978	112.996	4470	1360	1345	basaltic ash several mm thick in marl core from outcrop	~40	Oviatt, 1997
TM-3	Table Mountain	39.967	112.883	4500	1370	1350	thin, discontinuous lamination of basaltic ash; some pumice lumps up to ~5 cm diameter	9	Oviatt and others, 1994b
J06-30	Camels Back Ridge SW	40.103	112.943	4670	1420	1395	Dugway Proving Ground, Camels Back Ridge; coarse tephra, well bedded, well sorted, exposed in a gully; ~0.5 m thick	0	Clark and others, 2008
J06-31	Camels Back Ridge NW	40.142	112.955	4420	1350	1330	Dugway Proving Ground, Camels Back Ridge; thin lamination of fine basaltic ash; exposed in a gravel pit	~50	Clark and others, 2008
TOPAZ	Smelter Knolls east	39.447	112.810	4600	1400	1390	Topaz gravel pit; two beds of "sand with basalt granules"; gravel pit now gone, replaced by a landfill	0	Light, 1993
SME	Smelter Knolls east	39.403	112.853	4660	1420	1410	Smelter Knolls maar; possible source vent, but no glass found here	---	this paper

[1]*Refer to figure 2C.*

[2]*NAD83*

[3]*Altitudes are adjusted for the effects of differential isostatic rebound in the Bonneville basin using the formula of Currey (in Oviatt and others, 1992; Za = Zr – [(Zr – 1200)/(Zb –1200)][Zb – 1552], where Za = adjusted altitude; Zr = sample altitude; Zb = altitude of the Bonneville shoreline near the sample-collection site; 1552 = altitude of the Bonneville shoreline at Zenda, ID; 1200 = approximate basin-floor altitude at the time Lake Bonneville began to rise), so that altitudes at the time of deposition of the ash bed can be estimated. Results are rounded to the nearest 5 m.*

[4]*Stratigraphic thickness above base of Bonneville marl.*

form maars typically have tephra deposits that extend to greater distances from their sources than tephra erupted from cinder or scoria cones of equivalent volume (Fisher and Schmincke, 1984). The lateral extent and distribution pattern of the tephra deposit depends upon eruptive volume, grain size (which tends to be finer grained in phreatomagmatic eruptions), the prevalence of base surges, and prevailing winds. The Pony Express ash is distributed along a north-south extent of 125 km (75 mi). This is similar to the observed 130-km (80 mi) lateral extent of the Hansel Valley ash in the northern Bonneville basin (Miller and others, 2008). No potential source vents other than at Smelter Knolls have been found for the Pony Express ash, although the chemical composition of the ash is similar to that of Pahvant basalts, and it is possible that the vent is located in the Pahvant Butte area approximately 40 km to the southeast of Smelter Knolls.

In this paper we use the term "ash" for fine-grained (sand-size, or smaller) deposits of volcanic tephra, and the term "tephra" as a more general term that applies to pyroclastic material of variable composition or grain size larger than sand (Schmid, 1981).

STRATIGRAPHY

Where the Pony Express ash has been documented in the Sevier Desert basin, the ash is close to or at the base of the Bonneville deposits. Table 1 lists known locations of the Pony Express ash and the stratigraphic distance of the ash above the base of the Bonneville section at the different localities. At locality SK-2 (figure 2) the Pony Express ash is about 15 cm above the point in the marl where total inorganic carbon (TIC) and the ratio of aragonite to calcite begin to increase abruptly. In the Sevier Desert basin, the Bonneville marl is characterized by high levels of TIC and abundant aragonite (Oviatt and others, 1994a), and the abrupt increases in these parameters in core SK-2 could be interpreted as the initial transgression of the lake at that site. Ostracode faunas in the marl, however, tell a different story: below the Pony Express ash the ostracodes indicate marsh or wetland habitats, and above the Pony Express ash, ostracode faunas are typical of Lake Bonneville marl in the Sevier Desert (Oviatt and others, 1994a), suggesting that the ash is probably at the base of the Bonneville section here. As interpreted from the available information, at the time of the eruption of the Pony Express ash, Lake Bonneville was over 100 m (300 ft) deep in the Great Salt Lake basin and less than 20 m (60 ft) deep in the Sevier Desert basin.

Locality SR-6 consists of an exposure of the Bonneville marl in the eastern bluff of the Sevier River at an altitude of 1385 m (1375 m adjusted for isostatic rebound using the Currey isostatic-rebound-adjustment equation; Oviatt et al., 1992; 1375 m = 4500 ft). This is the lowest-altitude site that has been found in the Sevier Desert basin where the base of the Bonneville marl is exposed. At this site the Pony Express ash is disbursed in massive carbonate-rich muds that contain gastropod shells, and is overlain by finely laminated white marl.

About 23 km north of the ORBT in offshore sandy marl, the Pony Express ash is 2 cm above the base of the marl (at site CS-2-87), and 5 km (3 mi) north of this, at the point where the Pony Express road crosses the ORB, the ash is about 9 cm (3 in.) above the base of the marl (locality TM-3; figures 3 and 4). At TM-3 the Pony Express ash includes clasts of low-density scoria (or pumice) up to 2 cm (1 in.) in diameter, and the thickness of the ash bed ranges from 0 to about 1 cm (0.5 in.), with a modal thickness of 1 or 2 mm (0.04 or 0.08 in.). At locality TM-1, the Pony Express ash is about 40 cm (15 in.) above the base of the marl. The marl is not well exposed at TM-1, and was sampled in a shallow core (Oviatt and others, 1994a; Oviatt, 1997).

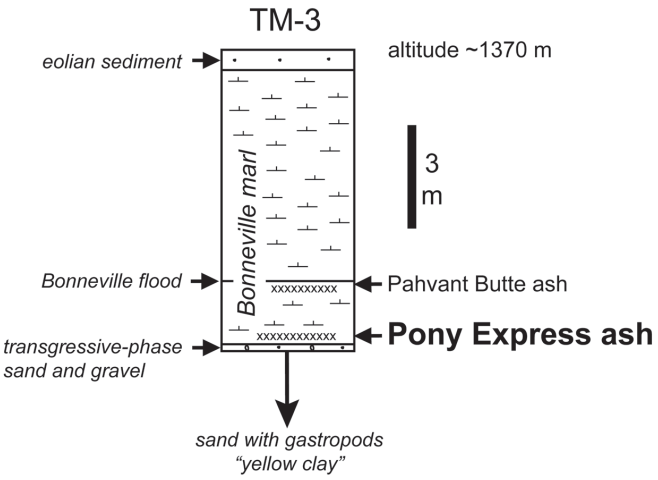

Figure 3. *Measured section of Lake Bonneville deposits at locality TM-3, on the east bluff of the Old River Bed, just south of the point where it is crossed by the Pony Express road (table 1; figure 2). Both the Pony Express ash and the Pahvant Butte basaltic ash are present in this section. For further information on this section, see Gilbert (1890), Oviatt (1987), and Oviatt and others (1994a, 1994b). Core TM-5 (Oviatt and others, 1994a) was taken at locality TM-3.*

On Dugway Proving Ground the Pony Express ash has been found at two localities, both on Camels Back Ridge (table 1; figure 2). At locality J06-30 the Pony Express tephra is at the base of the Bonneville section where it is exposed in a steep gully on the east flank of the ridge at an approximate altitude of 1420 m (1395 m when adjusted for differential isostatic rebound). At J06-30 the Pony Express tephra consists of coarse-grained tephra fragments (grain diameters up to 1 cm; 0.5 in.) that are well sorted and bedded with few locally derived clastic particles in the matrix (figure 6). This is a surprising exposure because the tephra is so clean and well bedded that it gives the impression of being on the flank of a tuff ring or tuff cone rather than on the flank of a hill composed of Paleozoic marine carbonate rocks with no volcano in sight. The chemical composition of the tephra here matches that of other Pony Express samples (figure 7).

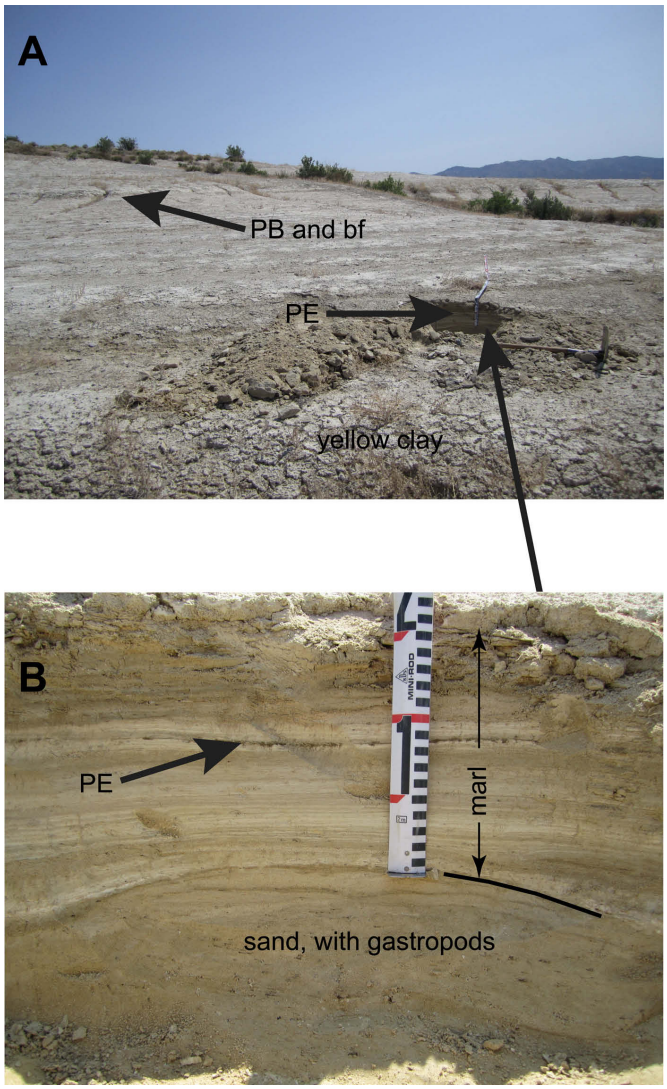

Figure 4. *(A) Photograph of the Bonneville section at location TM-3 on the east bluff of the Old River Bed, directly south of the crossing of the Pony Express road. (B) Close-up view of the Pony Express ash (PE) in the Bonneville marl in the shallow pit wall shown in figure 4A. The scale, numbered in decimeters, starts at the base of the Bonneville marl. PB = Pahvant Butte basaltic ash; bf = Bonneville flood marker horizon in the marl, about 2 cm higher than PB. (Photos by Oviatt, 2012.)*

A possible explanation for how the coarse, well-bedded tephra got to the deposition site at J06-30 on Camels Back Ridge is that the tephra was deposited on shore ice at the margin of Lake Bonneville close to the eruption site, then the ice broke free from the shore and floated to the place where it was lodged against Camels Back Ridge, then melted. The coarse tephra would then have been reworked by waves into the well-bedded deposit. A potential improbability of this explanation is that Camels Back Ridge is about 80 km north of the Smelter Knolls maar, and about 120 km north of the Pahvant Butte area, and was separated from the Sevier Desert basin by a narrow strait that was 1 km (0.6 mi) wide, or less, at the ORBT. A northward-flowing current, however, could easily have transported the floating ice through the strait.

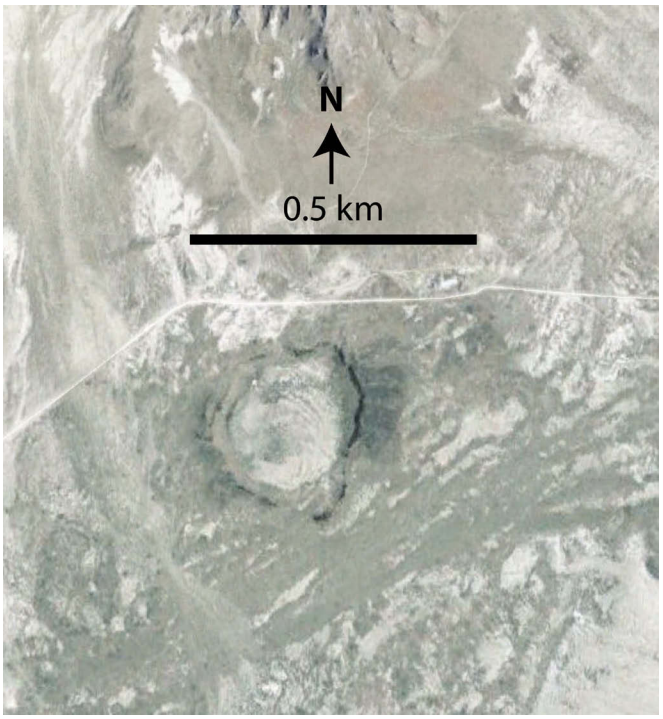

Figure 5. *Satellite image of the Smelter Knolls maar, western Sevier Desert (112.853° W; 39.403° N), a possible source vent for the Pony Express ash. The maar was produced by an eruption through an older basalt flow. Note the Lake Bonneville marl deposits (white) and beach gravels (dark) that overlie the basalt flow. Image from Google Earth (2012).*

About 4.5 km north of the coarse-tephra site (J06-30) on Camels Back Ridge, at locality J06-31, the Pony Express ash is exposed at an altitude of 1350 m (1330 m, adjusted for isostatic rebound; 1330 m = 4360 ft) in Bonneville marl in an abandoned gravel pit. At this site the lake water would have been roughly 70 m (330 ft) deep at the time of the eruption, and the Pony Express ash is fine grained and about 50 cm (20 in.) above the base of the marl. So far, this locality is the farthest north the Pony Express ash has been found.

GEOCHEMISTRY

The Pony Express ash contains fragments of vesicular basaltic glass with sparse phenocrysts of plagioclase. The paucity of phenocrysts indicates rapid quenching of the basalt magma near its liquidus, presumably in a phreatomagmatic eruption. The chemical composition of the glass has been determined by electron probe microanalysis (EPMA) using a Cameca model SX-50 electron microprobe at the University of Utah. Analytical conditions include 15 KeV accelerating voltage, 25 nA beam current, a defocused beam diameter of 15 µm (0.0006 in.), and a suite of natural mineral and synthetic standards.

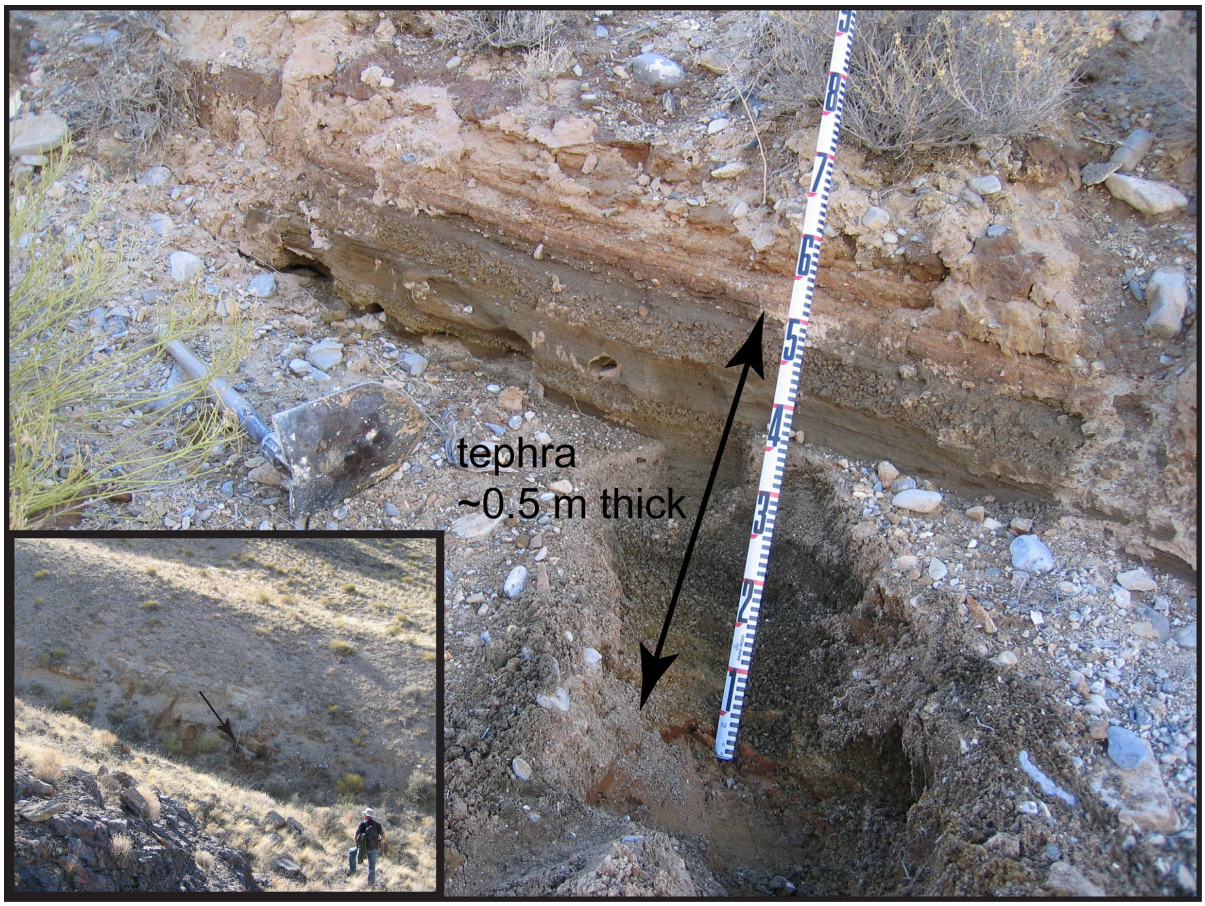

Figure 6. *Photograph of the exposure of tephra exposed in a gully at locality J06-30 on the east flank of Camels Back Ridge on Dugway Proving Ground. (Photos by Donald Clark [UGS], 2006).*

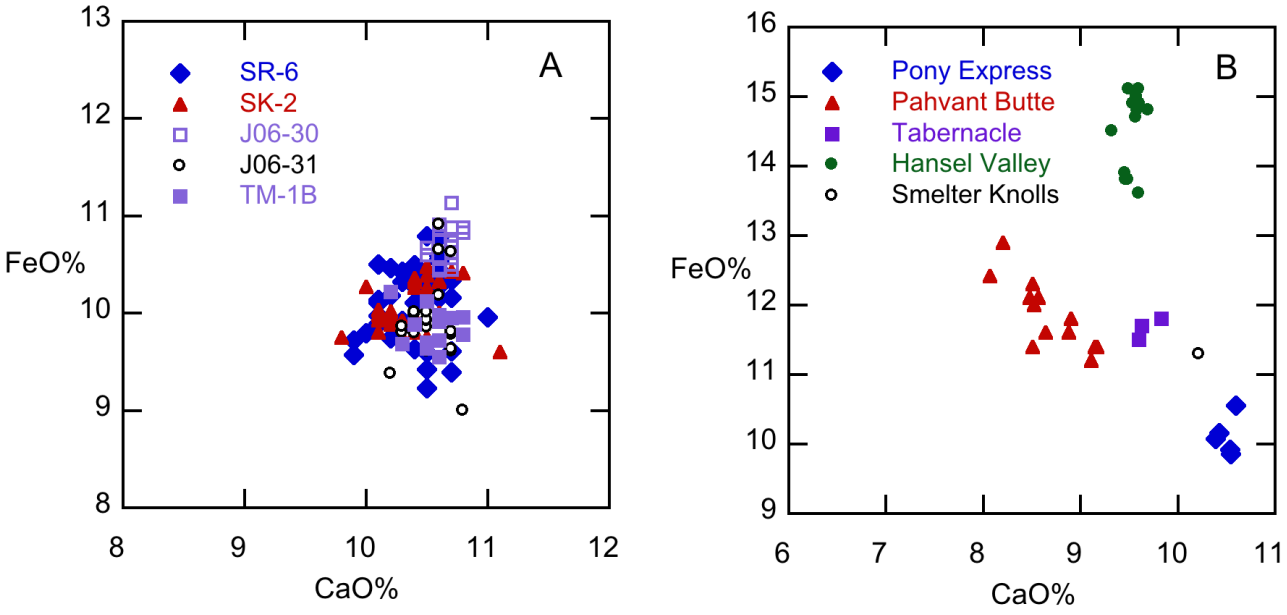

Figure 7. *(A) Electron microprobe analyses of glass in individual Pony Express shards (values in weight percent iron and calcium oxides). (B) Average analyses of glass from Pony Express and regional tephras (solid symbols) and whole-rock basalts (open symbols). PBR = Pahvant Butte ridge, TH = Tabernacle Hill, SK = Smelter Knolls (Oviatt and Nash, 1989; Turley and Nash, 1980).*

Average EPMA results for samples of the Pony Express ash are provided in table 2, and concentrations of FeO and CaO in 139 individual glass shards are illustrated on figure 7. The identical compositional populations in the samples confirm the stratigraphic correlations described above. Glass in the Pony Express ash can be distinguished from the other two regional tephras of similar age—the Pahvant Butte and Tabernacle Hill ashes—by higher CaO and lower FeO (figure 7b). The Pony Express glass has the composition of a tholeiitic basalt, characteristic of late Pleistocene volcanism of similar age in the Black Rock Desert (figure 2; Oviatt and Nash, 1989), and whole rock analyses of three Sevier Desert-basin basalts (Turley and Nash, 1980) are provided in table 2 for comparison. Glass from the Pony Express ash is similar in composition to Quaternary basalt that underlies and outcrops along the gentle ridge to the south of Pahvant Butte (BRD-6) and the basalt of Tabernacle Hill (BRD-15), but is distinct from the 300,000-yr-old basalt that makes up the rim of the maar at the southern end of Smelter Knolls (SK-66) that is a possible location of the Pony Express eruption (figure 5) (Turley and Nash, 1980). Alternatively, because the Pony Express ash closely resembles basalts of similar age in the Black Rock Desert, in the southern part of the Sevier Desert basin, it remains a possibility that its source lies there, perhaps concealed by younger lavas.

In addition to textural evidence of a phreatomagmatic eruption, such as fragmentation and formation of abundant glass, there is chemical evidence of interaction of the Pony Express ash-forming magma with saline brines or halite in evaporite deposits. Three of the samples—SK-2, J06-31, and TM-1B—have glass with anomalous and variable chlorine contents up to 1.1%, whereas samples SR-6 and J06-30 have consistently low values of ~0.05% (figure 8). In the case of SK-2, only three of 29 grains (10%) have elevated Cl contents, whereas in J06-31 and TM-1B, 75% and 86% of the glass fragments have elevated Cl, respectively. Cl varies systematically with Na (and with no other element analyzed) along a mixing line with NaCl (figure 8). Possible mechanisms for this behavior are either 1) post-depositional alteration or 2) magmatic assimilation of Cl-rich brine or halite. Because of the variation in Cl content between and within samples that were deposited in similar environments, we consider post-depositional alteration to be less likely. The alternative is that the magma encountered a subsurface NaCl brine or evaporite deposit that was partially incorporated into the magma, but because of the short eruptive time scale, was not homogenized throughout the magma volume. It has been established experimentally that basaltic magmas are under-saturated with respect to Cl, and chloride (Cl^-) is highly soluble, up to 2.0 weight percent, in basaltic melts at 1 bar pressure (Webster and others, 1999). As shown on figure 8, incorporation of as little as 2% NaCl is sufficient to account for the maximum Cl content of the Pony Express glasses. Coombs and others (2004) describe a similar circumstance in which the assimilation of high-Cl brines by Hawaiian basaltic magma resulted in Cl concentrations in glass of up to 1.68%.

Table 2. *Electron microprobe analyses of glass in Pony Express ash and selected whole-rock analyses of Sevier Desert-basin basalts. Values in weight percent. See table 1 for locations of samples.*

Sample	SK-2		SR-6		J06-30		J06-31		TM-1B		M07GB-115[a]		BRD-6	BRD-15	SK-66
													Pahvant Ridge	Tabernacle Hill	Smelter Knolls
n	29	sd	64	sd	9	sd	20	sd	14	sd	14	sd	wr	wr	wr
SiO_2	50.4	0.68	50.0	0.85	48.9	0.34	48.0	0.41	48.8	0.63	48.0	0.43	48.97	49.04	47.88
TiO_2	1.70	0.17	1.78	0.12	1.78	0.07	1.68	0.12	1.66	0.10	1.81	0.15	1.51	1.55	2.05
Al_2O_3	15.5	0.13	15.6	0.22	15.9	0.33	15.5	0.51	16.0	0.29	16.1	0.30	16.8	16.88	14.85
FeO	10.1	0.24	10.2	0.35	10.5	0.42	9.92	0.43	9.86	0.19	10.3	0.22	9.41	10.56	11.29
MnO	0.19	0.02	0.19	0.02	0.20	0.03	0.25	0.03	0.17	0.03	0.18	0.03	0.17	0.19	0.16
MgO	6.47	0.10	6.47	0.23	6.81	0.21	7.04	0.43	6.61	0.24	6.91	0.24	7.88	7.46	7.45
CaO	10.4	0.23	10.4	0.21	10.6	0.39	10.5	0.15	10.6	0.18	10.7	0.08	10.61	9.30	10.22
Na_2O	3.16	0.14	3.08	0.30	3.07	0.16	3.41	0.22	3.59	0.26	3.30	0.10	2.85	3.13	2.87
K_2O	0.89	0.05	0.86	0.05	0.68	0.08	0.73	0.08	0.79	0.07	0.67	0.05	0.71	0.89	0.81
P_2O_5	0.33	0.05	0.32	0.04	0.31	0.05	-	-	0.31	0.04	-	-	0.38	0.41	0.44
F	0.06	0.04	0.10	0.03	0.02	0.03	0.06	0.03	0.10	0.04	-	-	-	-	-
Cl	0.11	0.03	0.06	0.03	0.04	0.02	0.39	0.29	0.66	0.34	-	-	-	-	-
Sum	100.4	0.39	100.2	0.51	100.0	0.54	97.5	0.57	100.2	0.46	98.0	0.72	99.43	99.48	99.72
less O=F,Cl	0.05	0.02	0.05	0.02	0.02	0.02	0.11	0.06	0.19	0.07	-	-	-	-	-
Total	100.3	0.39	100.1	0.50	100.0	0.52	97.3	0.54	100.0	0.48	98.0	0.72	99.43	99.48	99.72

n = number of glass fragments analyzed; sd = standard deviation; wr = whole rock analysis.

[a] This is the same sample as J06-30, but analyzed by Elmira Wan in the USGS laboratory in Menlo Park, CA (personal communication, Elmira Wan and David Miller, 2008).

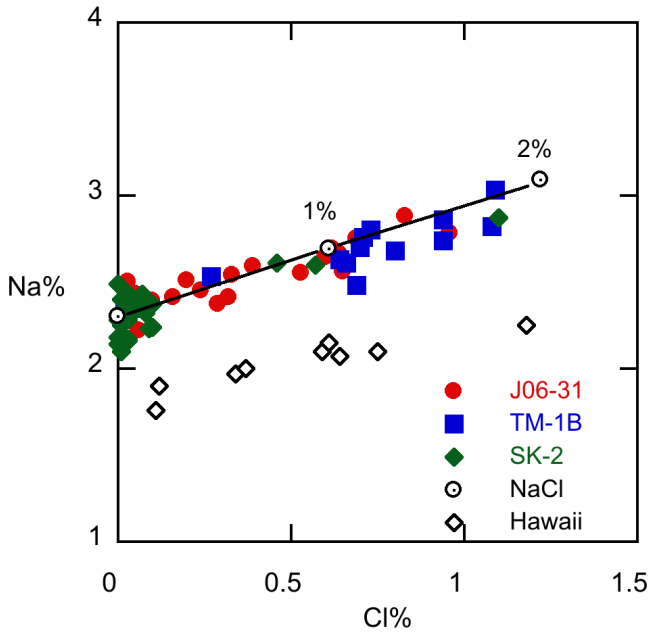

Figure 8. *Electron microprobe analyses of Cl in Pony Express glass (values in weight percent). Solid line represents mixing between low-Cl Pony Express glass and NaCl. Hawaii basalt data for comparison are from Coombs and others (2004).*

AGE

There is currently no method to directly date the Pony Express ash, but its age is estimated using the radiocarbon ages of gastropods collected from similar stratigraphic levels near the base of the Bonneville marl in the Sevier Desert basin. A sample of gastropods at an altitude of 1390 m (4560 ft) in the basin (locality LRSW-6; figure 2C) yielded a radiocarbon age of 19,920 ± 230 ^{14}C yr B.P. (Oviatt, 1989) (calibrated to between about 23,500 and 24,000 cal yr B.P. using CALIB6.0; Reimer and others, 2009; Stuiver and Reimer, 1993). In a small-diameter sediment core (core RK-8; figure 2C) collected about 7 km north of site SR-6 at an altitude of 1385 m (about the same altitude as SR-6), a radiocarbon age for gastropod fragments close to the base of the marl was 20,400 ± 70 ^{14}C yr B.P. (between 24,200 and 24,500 cal yr B.P.). Pony Express ash is not present at either LRSW-6 or RK-8, but the radiocarbon ages provide an estimate of the time that Lake Bonneville flooded the Sevier Desert basin.

At the Topaz gravel pit site (table 1), Light (1993) reported four radiocarbon ages for gastropods from the transgressive-phase sands and gravels at the base of the Bonneville section, which included "sand with basalt granules." Those ages ranged between 20,025 ± 155 and 20,295 ± 155 ^{14}C yr B.P., and are statistically indistinguishable (Light, 1993, figure 24); the average of these ages is roughly 20,200 ^{14}C yr B.P. (~24,000 cal yr B.P.). Considering the potential uncertainties, all available radiocarbon ages associated with the Pony Express ash are consistent with each other, and suggest that the age of the Pony Express ash is close to 20,000 ^{14}C yr B.P. (24,000 cal yr B.P.).

SUMMARY

Basaltic ashes are used as stratigraphic markers in Lake Bonneville deposits. The Pony Express basaltic ash was erupted from a vent somewhere in the Sevier Desert basin, possibly from a maar southeast of Smelter Knolls or from a concealed vent in the vicinity of Pahvant Butte, soon after Lake Bonneville had transgressed high enough to flood into the basin (figure 1). The Pony Express ash is found at or near the base of the Bonneville marl below altitudes of 1400 m (4600 ft) in outcrops as far as about 120 km apart (figure 2C), and was erupted after the Stansbury oscillation and formation of the Stansbury shoreline in the Great Salt Lake basin. The chemical composition of the Pony Express ash is similar to that of other basalts in the Sevier Desert, particularly those in the Pahvant Butte area. Radiocarbon ages of gastropods associated with the base of the Bonneville marl in the Sevier Desert basin indicate an age for the Pony Express ash of about 20,000 ^{14}C yr B.P. (~24,000 cal yr B.P.). Approximate ages, and isostatically adjusted altitudes of the eruptive vents, of the known basaltic ashes in Lake Bonneville deposits are: Hansel Valley ash (30,800 cal yr B.P., 1325 m, 4350 ft); Pony Express ash (24,000 cal yr B.P., 1400 m, 4600 ft); Pahvant Butte ash (18,600 cal yr B.P., 1545 m, 5070 ft); and Tabernacle Hill ash (17,700 cal yr B.P., 1440 m, 4720 ft) (Oviatt and Nash, 1989; Oviatt and others, 1992; Miller and others, 1995, 2008). A unique characteristic of the Pony Express ash is elevated levels of Cl that indicate interaction of the Pony Express magma with Cl-rich brines or evaporites during the phreatomagmatic eruption.

ACKNOWLEDGMENTS

We are grateful to a number of people who have helped over the years with documenting the Pony Express ash, including Tracey Felger (USGS), who found the Pony Express ash in marl exposures along the Old River Bed near TM-3 and alerted Oviatt; numerous students who have worked on lake sediments in the sedimentology lab at Kansas State University; and Elmira Wan, USGS, who analyzed a sample of Pony Express tephra collected by David Miller. The electron microprobe laboratory at the University of Utah is supported in part by the National Science Foundation, the College of Mines and Earth Sciences, and the Department of Geology and Geophysics. Additionally, we are grateful for the superb polished mounts of Quintin Sahratian used in analysis. Partial support of part of this work came from STATEMAP funds through the Utah Geological Survey. David Miller (USGS), Eric Christiansen (Brigham Young University), Donald Clark (UGS), Mike Hylland (UGS), and Grant Willis (UGS) gave us valuable comments in their reviews of the paper.

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