Journal of Archaeological Science 40 (2013) 4466–4476

Contents lists available at SciVerse ScienceDirect

Journal of Archaeological Science

journal homepage: http://www.elsevier.com/locate/jas

Dating North America's oldest petroglyphs, Winnemucca Lake subbasin, Nevada

L.V. Benson [a,*], E.M. Hattori [b], J. Southon [c], B. Aleck [d]

[a] Museum of Natural History, University of Colorado, 602 Pine Street, Boulder, CO 30302, USA
[b] Nevada State Museum, Carson City, NV 89701, USA
[c] Earth System Science, University of California, Irvine, CA 92697, USA
[d] Pyramid Lake Paiute Tribe Museum and Visitor Center, Nixon, NV 89424, USA

ARTICLE INFO

Article history:
Received 30 March 2013
Received in revised form
14 June 2013
Accepted 15 June 2013

Keywords:
Petroglyphs
Rock art
Great Basin
Winnemucca Lake
Pyramid Lake

ABSTRACT

On the west side of the Winnemucca Lake subbasin, Nevada, distinctive deeply carved meter-scale petroglyphs are closely spaced, forming panels on boulder-sized surfaces of a partially collapsed tufa mound. The large, complex motifs at this side are formed by deeply carved lines and cupules. A carbonate crust deposited between 10 200 and 9800 calibrated years B.P. (ka) coats petroglyphs at the base of the mound between elevations of 1202 and 1206 m. Petroglyphs above the carbonate crust are carved into a branching form of carbonate that dates to 14.8 ka. Radiocarbon dates on a multiple-layered algal tufa on the east side of the basin, which formed at an elevation of 1205 m, as well as a sediment-core-based total inorganic carbon record for the period 17.0–9.5 ka indicate that water level in the Winnemucca Lake subbasin was constrained by spill over the Emerson Pass Sill (1207 m) for most of the time between 12.9 ± 0.3 and ≥9.2 ka. These and other data indicate that the lake in the Winnemucca Lake subbasin fell beneath its spill point between 14.8 and 13.2 ka and also between 11.3 and 10.5 ka (or between 11.5 and 11.1 ka), exposing the base of the collapsed tufa mound to petroglyph carving. The tufa-based ^{14}C record supports decreased lake levels between 14.8–13.2 ka and 11.3–10.5 ka. Native American artifacts found in the Lahontan Basin date to the latter time interval. This does not rule out the possibility that petroglyph carving occurred between 14.8 and 13.2 ka when Pyramid Lake was relatively shallow and Winnemucca Lake had desiccated.

Published by Elsevier Ltd.

1. Introduction

1.1. Early American art forms

Recent Paleoindian research in the Americas (Dillehay et al., 2008; Gilbert et al., 2008; Overstreet and Stafford, 1997) suggests that humans reached the Americas prior to the Clovis period, which began ~13 100 calendar years before present (hereafter 13.1 ka). The earliest art in the Americas is arguably represented by a fragmented fossil bone from Florida (Purdy et al., 2011). The bone appears to be engraved with the figure of a mammoth, whose fossil remains date no later than 13 ka in eastern North America (Faith and Surovell, 2009; Grayson and Meltzer, 2003). The earliest petroglyph in South America is a pecked anthropomorphic figure in central-eastern Brazil; it has a minimum age of ~10.6 ka and may be as old as 12 ka (Neves et al., 2012). Prior to our study, the oldest petroglyphs in North America (Cannon and Ricks, 1986) were represented by a panel of deeply incised, tightly clustered geometric petroglyphs from a cliff face along a basalt ridge at Long Lake in south-central Oregon. These petroglyphs were subsequently partly buried by the 7.63 ka Mount Mazama tephra (Zdanowicz et al., 1999). Here we report on early Archaic/Paleoindian petroglyphs from the Winnemucca Lake subbasin, Nevada, that were carved sometime between 14.8 ± 0.2 and 10.3 ± 0.1 ka.

1.2. The Winnemucca Lake petroglyph site

The Lahontan Basin (Fig. 1A) is located on the western edge of the Great Basin of the western USA. Three subbasins occupy the western side of the Lahontan Basin, Pyramid Lake, Winnemucca Lake, and the Smoke Creek-Black Rock Desert subbasins. On the western edge of the Winnemucca Lake subbasin, Nevada, just inside the eastern boundary of the Pyramid Lake Indian Reservation (site WDL12, Fig. 1B), numerous deeply carved meter-scale

* Corresponding author. Tel.: +1 303 4495529.
E-mail address: lbenson@usgs.gov (L.V. Benson).

0305-4403/$ – see front matter Published by Elsevier Ltd.
http://dx.doi.org/10.1016/j.jas.2013.06.022

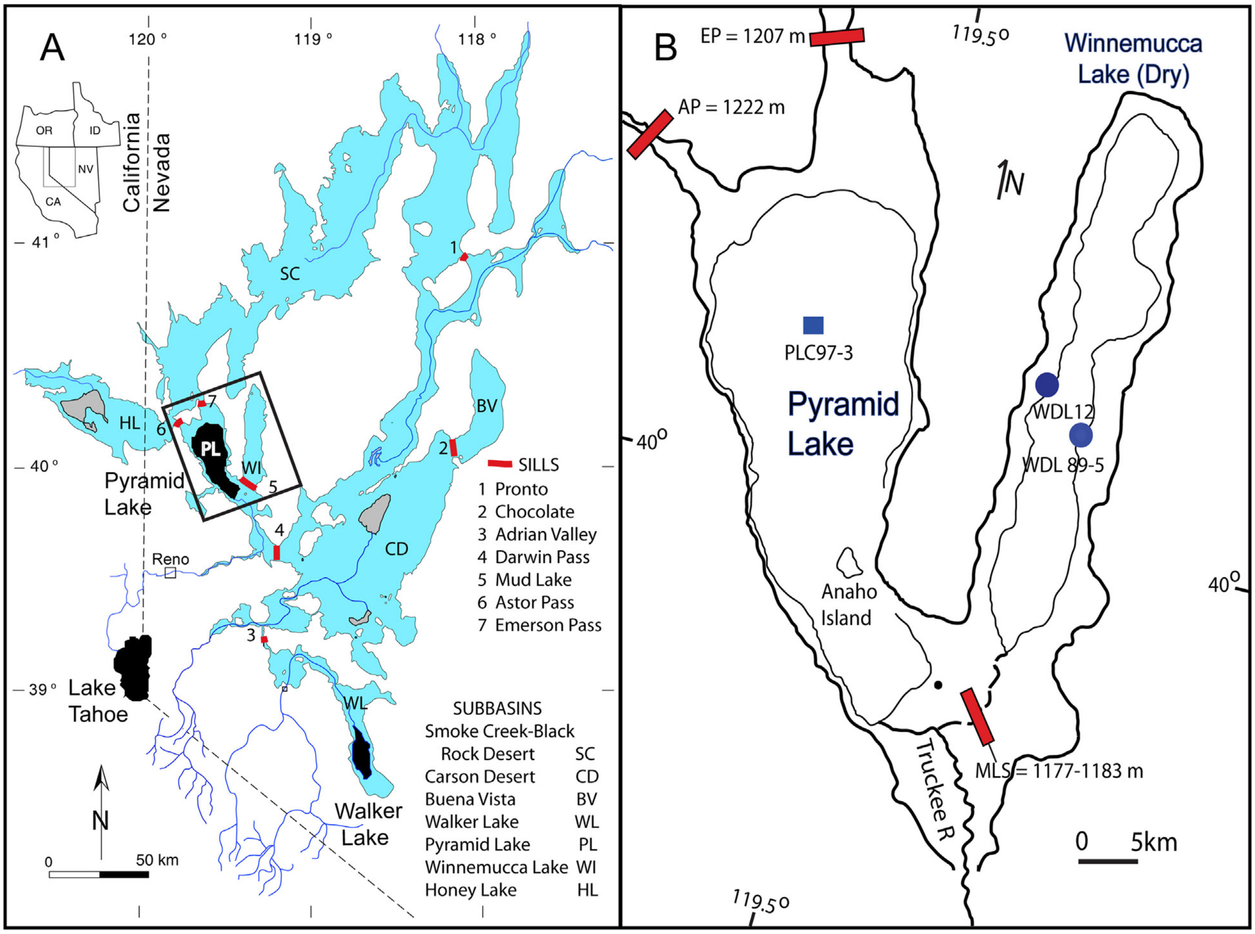

Fig. 1. A. The Lake Lahontan Basin, which contains seven lake subbasins separated by seven spill points (sills); B. The Pyramid and Winnemucca lake subbasins, Nevada. Astor Pass, Emerson Pass, and Mud Lake Slough spill points (dark red rectangles) are labeled, respectively, AP, EP, and MLS. Historic pre-irrigation surface areas of Pyramid and Winnemucca Lakes are bounded by thin black lines. WDL12 is the petroglyph site; WDL89-5 is the algal tufa site. The PLC97-3 sediment core site is shown as a blue square. Petroglyphs coated by the carbonate crust in A and B have been highlighted in Supplementary Fig. 2. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

petroglyphs are closely spaced, forming panels on boulder-sized surfaces of a partially collapsed tufa mound (Fig. 2, Supplementary Fig. 1).

The Winnemucca Lake petroglyph site 26Wa3329 (also known by its earlier site designation NV-Wa-29 in the University of California archaeological site files) was recognized as an unusual, and possibly, very early petroglyph site by Connick and Connick (1992). Their survey of Great Basin, California, and Southwestern archaeological and ethnographic literature revealed a suite of attributes that distinguished the Winnemucca Lake petroglyphs from the vast majority of other Great Basin petroglyph and pictograph sites. The motifs at this side are large and complex. Deeply carved lines ("grooves") and dots ("cups" or cupules) form complex designs. The carvings are commonly 1–2 cm deep with cupules occurring on vertical versus horizontal surfaces. Some of the petroglyph motifs are represented elsewhere in the western Great Basin but they are neither oversized nor deeply incised. Missing from this site are some of the more common younger Great Basin petroglyph motifs, including zoomorphs, anthropomorphs, and handprints. Connick and Connick (1992) suggested that the Winnemucca Lake petroglyphs represented various meteorological symbols, e.g., clouds and lightning, associated with ethnographic and archaeological cultures from the American Southwest and southern California. Our analysis, however, found closer technological, chronological, and design concordance with a site in south central Oregon, as well as other localities in the western Great Basin.

During an early trip to the petroglyph site, the senior author noticed that some petroglyphs on an east facing panel near the base of the tufa mount were partially coated with a thin white carbonate crust that reached an elevation of ~1206 m (Fig. 3), the approximate elevation of the northern spill point (Emerson Pass at ~1207 m) of the Winnemucca and Pyramid lake subbasins to the Smoke Creek-Black Rock Desert subbasin (Fig. 1). Above the carbonate crust, it is apparent that the petroglyphs were originally carved into a branching form of tufa (Benson, 1994), which was deposited between 16.2 and 14.8 ka (Supplementary Table 1, BT samples in Fig. 4). In some instances, the lower portions of several elements on this panel are coated by the carbonate crust while the upper portions of the same elements remain uncoated or are only lightly coated because they are situated above the boundary for the zone of carbonate precipitation at ~1206 m. Some petroglyph elements on these panels are partially or entirely covered by varying thicknesses of the carbonate crust and motif details obscured.

The carbonate crust appears to thin in an upward direction, probably indicating deposition during differing overflow velocities; the higher the overflow velocity the higher the elevation of carbonate deposition at the petroglyph site which lies far south of the

Fig. 2. Petroglyph site WDL12 (archaeological site 26Wa3329) on the west side of the Winnemucca Lake subbasin. The tree-form petroglyph near the left side of the collapsed tufa mound is ~70 cm in length.

Emerson Pass spill point. Petroglyphs covered by the carbonate crust below the 1206-m line can be seen in Fig. 2A and B. These petroglyphs have also been highlighted in Supplementary Fig. 2.

On the northernmost boulder (Supplementary Fig. 2A), motifs that exhibit thicker carbonate crust on their lowermost segments include the following from south to north on the east facing panel: four stacked rows of short, vertical parallel lines; a series of vertical chain-like petroglyphs comprised of oval- to diamond-shaped elements, some of which exhibit enhanced interiors by use of circles and perforation of the outer tufa layer; a very deeply incised set of three curved, diagonal lines; and a complex design comprised of series of very deeply incised vertical, straight and sinuous lines bordered by a lower horizontal line.

Another tufa boulder (Supplementary Fig. 2B) exhibits the following motifs: horizontal diamond and circular elements joined to each other or linked by lines; additional, single circular-, diamond- and ovoid-shaped motifs; and lowermost motif comprised of four or more, short vertical lines atop a horizontal line. A complex rayed motif occupies the northern end of this panel. Similar vertical, chain-like motifs and variants of the rayed motif occur elsewhere at the Winnemucca Lake site, and variants of the short vertical line motif and the very deeply incised, paired diagonal curved line motif also occur at Long Lake as Great Basin Carved Abstract style petroglyphs.

The objective of this study is to ascertain the age of the Winnemucca Lake petroglyphs. We do this by first bracketing their time of carving by dating (^{14}C) the branching-form carbonate into which they were carved and the thin layer of carbonate that coats them. The tufa mound was accessible to petroglyph carving only when lake level fell below its spill point to the Smoke Creek-Black Rock Desert subbasin; i.e., below 1207 m. In order to determine when the lake was at its 1207-m spill level, we dated two layered algal tufas that formed in shallow water at an elevation of ~1206 m on the eastern side of the Winnemucca Lake subbasin. We also obtained a continuous record of total inorganic carbon (TIC) deposition between 17.0 and ~9.5 ka from a Pyramid Lake sediment core (PLC97-3) which was used to determine when the lake fell below its spill level.

2. Methods

2.1. Sediment coring and TIC measurement

Pyramid Lake core PLC97-3 was recovered in 94 m of water (Fig. 1B). Given evidence of shallow-water conditions and erosive activity above a sediment depth of 1.95 m, PLC97-3 was sampled starting at 1.95 m at the top of a laminated sedimentary unit. Continuous 10-mm-thick samples were taken from the 2.43 m of sediment below the 1.95 m depth. Parts of the core, which contained turbidites and slumped sediments, were subtracted from the core and its length readjusted to 4.0 m. Age models for this core (Fig. 5) were based on continuous measurements of paleomagnetic secular variation (PSV) that were matched to a well-dated PSV type curve, which had been correlated via marine sedimentary records to the GISP2 ice core (Benson et al., 2012; Lund, 1996, 2001a,b). Each 10-mm-thick sample averages a time span of 55 years. Each sample was combined with deionized water, shaken, and centrifuged for 15 min at 20 000 rpm using a Sorval Superspeed RC2B. After centrifugation, the conductivity of the supernatant was measured and the supernatant discarded. This procedure was repeated until the specific conductivity of the supernatant was <3 times the conductivity of Boulder, Colorado, tap water. Samples were then freeze-dried and homogenized. Values of TIC were determined at the USGS Boulder Laboratory using a UIC Model 5012 carbon dioxide coulometer. A detailed sedimentologic description of PLC97-3 can be found in Benson et al. (2002).

The elevation (1207 m) of the bedrock sill at Emerson Pass was obtained by surveying (Mifflin and Wheat, 1971). The elevation (1205) of the algal tufa (WDL89-5) on the eastern side of the Winnemucca Lake subbasin (Fig. 1) was estimated using a digital altimeter and was reported in Supplementary Table 7 of Benson et al. (2012).

The elevation of the top of the white carbonate crust (1206 m) at the Winnemucca Lake petroglyph site was measured using a Garmin GPSmap 60CSx. The accuracy of the elevations at each of these sites is estimated to be, respectively, <1 m, ±3 m and ±2 m.

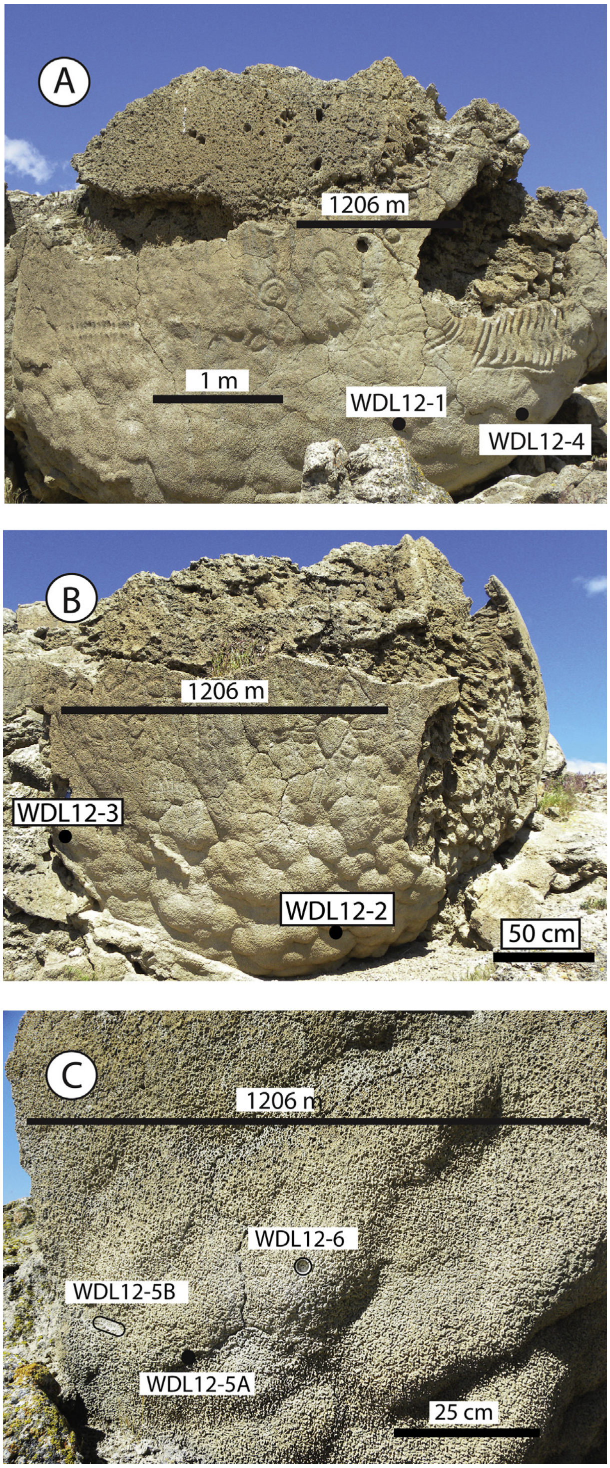

Fig. 3. Location of samples taken from three carbonate coated tufa boulders. The line at 1206 m indicates the upper limit of the carbonate coating. Sample WDL12-5B was peeled from the surface of the carbonate coating; WDL 12-6 was a short core taken through the coating. All other samples were taken by abrading the surface of the carbonate coating with a Dremel diamond bit.

Samples from were removed from the upper two layers of the algal tufa (WDL89-5B) using a Dremel diamond saw in order to determine whether they contained diatoms. The samples were processed using 30% hydrogen peroxide, 37% hydrochloric acid, and 70% nitric acid. The resulting solution was deflocculated using 5%

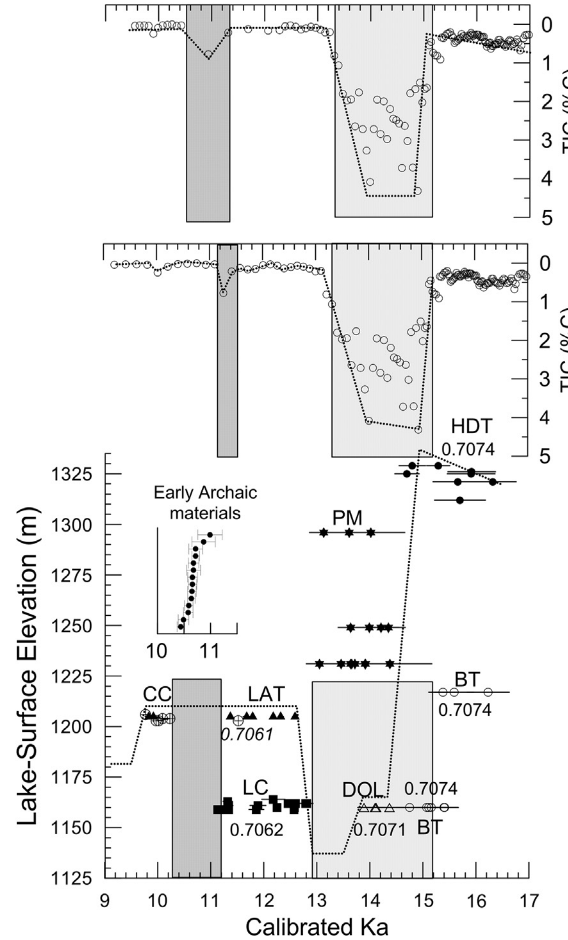

Fig. 4. Circles in the top two graphs bounded by dotted lines indicate total inorganic carbon (TIC) concentrations in core PLC97-3. Two different age models were used to construct the two graphs (see Fig. 5). The dotted line in the lower part of the figure depicts lake levels in the Pyramid Lake subbasin based on dated materials from the Pyramid and Winnemucca lake subbasins. Calibrated ^{14}C dates on Lahontan Basin Archaic materials are shown as filled dots within inset; error bars indicate 1 standard deviation. HDT, BT, PM, DOL, LC, LAT, and CC stand, respectively for highstand dense tufa, branching tufa, soluble packrat middens, dolomite, laminated calcite, layered algal tufa, and carbonate crust. Vertical shaded rectangles indicate most probable times of petroglyph carving. Mean $^{87}Sr/^{86}Sr$ values for tufa types are shown as five digit numbers. The $^{87}Sr/^{86}Sr$ value of the dense tufa underlying the carbonate crust at the petroglyph site (open circle with cross) is shown as an italicized five digit number.

sodium pyrophosphate and the residual sediment was mounted in Naphrax (r.i. –1.71). Both samples contained well-preserved *Stephanodiscus hantzschii*. This is a planktonic freshwater species found today in lakes in British Columbia.

2.2. Carbonate sampling

Seven carbonate samples were collected at the petroglyph site (WDL12). Samples were not collected from the carved lines and cupules comprising the petroglyphs. Three pairs of samples (WDL12-1 and -4, WDL12-2 and -3, WDL12-5A and -5B) of the same 2-mm-thick carbonate crust that coats the petroglyphs at the base of the site were collected from the faces of three broken tufa boulders (Fig. 3). All but WDL12-5B were sampled using a Dremel diamond grinding tool. Sample WDL12-5B was "peeled" from the tufa surface. Sample WDL-6 (Fig. 3C) is a 15-mm-long core collected from the same boulder as WDL12-5A and -5B. The core was taken in

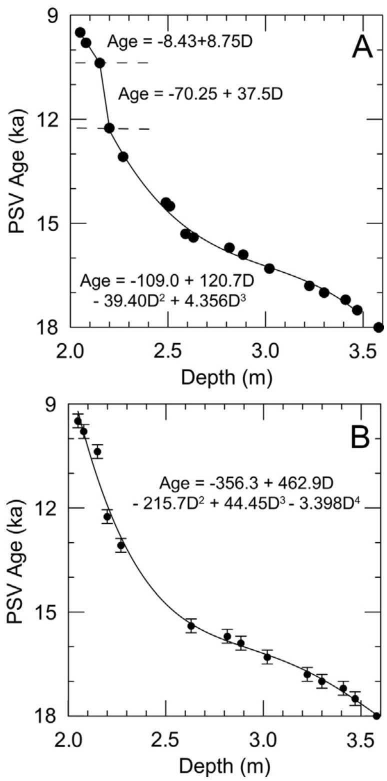

Fig. 5. Two PSV-based age models for core PLC97-3. Black dots are PSV ages acquired by matching the PSV record in PLC97-3 to the PSV record in well-dated sediment cores. Dashed lines in A. indicate the limits of each polynomial fit to PSV subsets. PSV ages are accurate within ±200 years.

order to penetrate a dense carbonate layer (WDL12-6B) that was located beneath the carbonate crust.

Radiocarbon ages were obtained on non-archaeological tufas. Two layered algal tufas (WDL89 5B and 5C) that had been collected in 1989 from the east side of the Winnemucca Lake subbasin were subsampled using a diamond Dremel bit. Powdered samples from five layers in WDL89 5B and three layers in WDL89 5C were collected (Fig. 6). Both algal tufas were coated with a carbonate crust similar in appearance to the crust coating the base of the petroglyph site. Carbonate crusts at both sites (WDL12 and WDL89) formed at elevations slightly below 1206 m.

2.3. *Processes that shift the ^{14}C age of samples from their times of deposition*

All 15 carbonate samples were ^{14}C dated at the University of California-Irvine W.M. Keck Carbon Cycle Accelerator Mass Spectrometry Laboratory. All data in this paper were calibrated using Stuiver and Reimer, 1993 (version 5.0) together with intcal09.14c.

2.3.1. *The reservoir effect*

In some situations, ^{14}C dates on lacustrine carbonates are subject to a "reservoir effect", wherein, the presence of excess dead carbon can shift the apparent ^{14}C ages of carbon-bearing materials to values older than their actual dates of formation/deposition. Dead carbon can enter the lake via surface-water input as well as diffusion/advection across the sediment–water interface. Atmospheric CO_2, containing modern carbon, can minimize and even eliminate the reservoir effect if the gas exchange rate across the air–water interface is sufficiently rapid.

The overflow of water from the Pyramid-Winnemucca Lake complex to the Smoke Creek-Black Rock Desert can lessen and even eliminate a preexisting reservoir effect. Spill across the Emerson

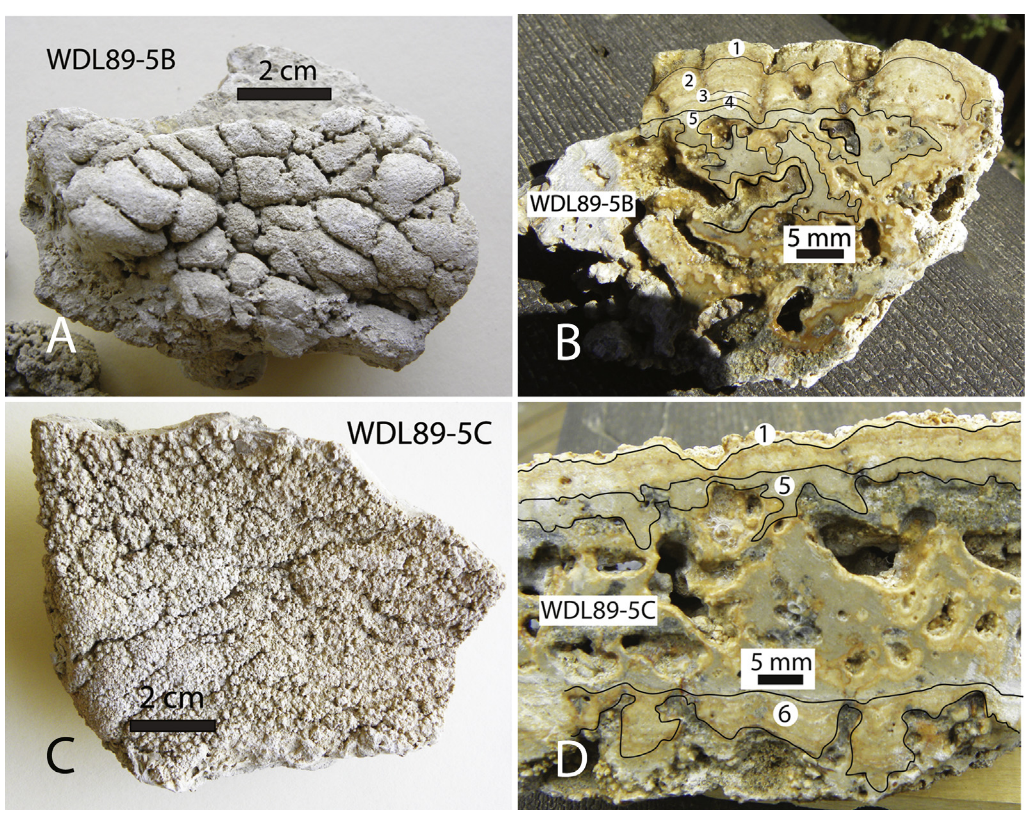

Fig. 6. A. Algal tufa sample WDL89-5B; B. cross section through WDL89-5B showing locations of five ^{14}C dated samples; C. algal tufa sample WDL89-5C; D. cross section through WDL89-5C showing locations of three ^{14}C dated samples.

Pass Sill (Fig. 1) implies that the Truckee River was discharging a large volume of water to the lake occupying the Pyramid and Winnemucca lake subbasins. The increasing fraction of modern-carbon-bearing snow-melt runoff relative to the fraction of dead-carbon-bearing groundwater in the Truckee River during times of spill over Emerson Pass resulted in declines in the fraction of dead carbon in the river as well as a reduction in the ionic strength (salinity) of lake water. Gas (CO_2) exchange operates more efficiently as the concentration of dissolved inorganic carbon (DIC) decreases, effectively removing the dead carbon dissolved in the lake. Therefore, increased stream-flow discharge to a lake and (or) increased spill from the lake to an adjacent subbasin tend to minimize a lake's reservoir effect.

Carbonates found at elevations slightly below 1207 m were deposited when the lake was hydrologically open and spilling across the Emerson Pass Sill. Carbon isotopes in the total organic carbon fraction (TOC) fraction of lake sediment generally have the same ratios as carbonates (e.g., tufas) deposited at the same time, given that the have the same carbon source, the DIC in lake water. We can, therefore, assess the magnitude of the reservoir effect during times of spill by comparing the PSV-based age of a sediment sample with the calibrated ^{14}C age of the TOC fraction in that sample. During the rise of Lake Lahontan (30–25 ka) and during its intermittent spill to the Carson Desert subbasin (25–18 ka) (Fig. 7A), the calibrated ^{14}C ages of the TOC fraction in four sediment samples were less than or equal to their PSV ages (Fig. 7B), demonstrating that a substantial reservoir effect was not present in Lake Lahontan during its spill to an adjacent subbasin. Therefore, the ^{14}C ages of tufas deposited during spill over the Emerson Pass Sill should not be expected to have been offset by a substantial reservoir effect.

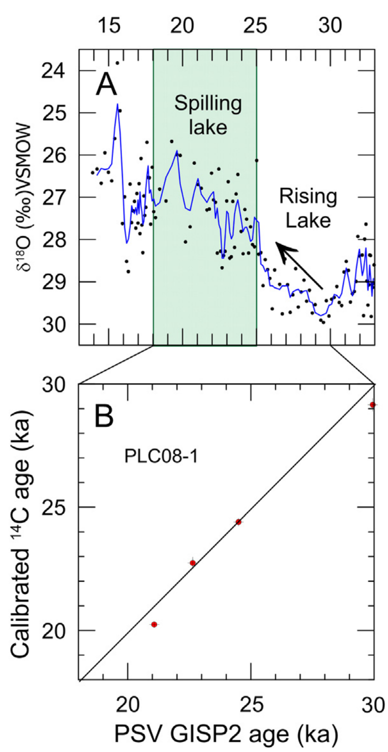

Fig. 7. A. Relative elevation of Lake Lahontan between 33 and 16 ka (Benson et al., 2012). Decreasing values of $\delta^{18}O$ in this sediment core indicate increasing lake elevation or spill rate across the Darwin Pass Sill into the Carson Desert subbasin. The arrow indicates lake-level rise between 30 and 25 ka, and the shaded area indicates an interval of intermittent spill across Darwin Pass Sill between 25 and 17 ka; B. Calibrated ^{14}C ages of four sediment samples in Pyramid Lake core PLC08-1 versus their PSV-based ages (Benson et al., 2012). The PSV-based ages have been tied to the GISP2 ice-core layer-counted chronology. The data indicate the lack of a reservoir effect when the lake in the Pyramid Lake subbasin was rising and when it was spilling to an adjacent subbasin.

2.3.2. The addition of modern carbon during subaerial exposure

The addition of modern carbon during subaerial exposure can shift the age of deposition of a carbonate to younger values. Addition of modern carbon to the porous carbonate crusts that coat tufas at both WDL12 and WDL89-5 sites is likely to have occurred throughout the Holocene after the crust was subaerially exposed to low-pH precipitation. Rain water may have dissolved part of the crust and the resulting solution, which contained both old and modern carbon, would have subsequently warmed, causing $CaCO_3$, containing some modern carbon, to reprecipitate within the pore spaces in the carbonate crust. To check for contamination with secondary carbon, 50% of each of eight algal layers was leached prior to AMS ^{14}C analysis. We later decided to remove (acid leach) differing amounts (20, 40, 50, 60, and 80%) of five subsamples from WDL89 5C-1 to determine how the age of the porous carbonate crust changed with amount leached. WDL89 5C-1 was chosen for this experiment, given that it was most likely to have suffered secondary contamination with modern carbon. The results of this experiment (Table 1) indicated that the age of the sample increased with the amount of sample removed. As a result, we decided to remove 80% of each sample prior to AMS ^{14}C analysis, except for WDL89 5B-5 for which insufficient material remained.

It should be noted that the ^{14}C date of WDL89 5C-1 never "leveled off" as a function of leaching (Supplementary Fig. 3). This implies the existence of a refractory carbonate contaminant in the carbonate crust and suggests that the resulting ^{14}C ages obtained on samples of the carbonate crust from both the collapsed tufa mound and the algal tufas represent minimum values.

2.4. Strontium-isotope analyses

Nine samples (five algal layers, three carbonate crusts from the petroglyph site, and the dense carbonate found below the carbonate crust at the WDL12 site) were also subjected to $^{87}Sr/^{86}Sr$ analysis. The $^{87}Sr/^{86}Sr$ analyses were done at the University of Colorado heavy-isotopes laboratory. The error in the $^{87}Sr/^{86}Sr$ analyses was <1 unit in the fifth decimal place. Previous $^{87}Sr/^{86}Sr$ analyses of Pyramid Lake tufas (Benson and Peterman, 1995) are listed in Supplementary Table 1.

3. Results and discussion

3.1. Tufa-based elevation history of Lake Lahontan

The ^{14}C-dated tufa sequence in Fig. 4 indicates that Lake Lahontan receded from its highstand between 15 and ~14.5 ka. Dolomite formed in the Pyramid Lake subbasin between ~14.4 and 13.9 ka, implying the existence of a relatively shallow, saline lake. The oldest dolomite date (14.4 ka) is considered the most reliable as the porous dolomite may have been subsequently contaminated with younger carbonate precipitated from Pyramid Lake. There is no record of carbonate deposition between 13.9 and 12.8 ka, suggesting the lake may have fallen below 1160 m at this time. Between 12.8 and 11.1 ka, laminated low-magnesium calcite was deposited on the western edge of the Pyramid Lake subbasin, indicating the presence of a deep freshwater lake.

3.2. Age of the branching tufa into which the petroglyphs were carved

Petroglyphs found above the carbonate crust have been carved into a branching form of tufa. The ages and $^{87}Sr/^{86}Sr$ values of the

Table 1
Calibrated ^{14}C ages and $^{87}Sr/^{86}Sr$ analyses of carbonate samples from sites WDL89 and WDL12 on, respectively, the east and west sides of the Winnemucca Lake subbasin.

Sample name	Layer type	Ele. (m)	UCIAMS no.	Leach (%)	^{14}C Age (BP)	±	Calib age $1-\sigma$ range	Area (%)	Calib age $2-\sigma$ range	Area (%)	Calib $1-\sigma$ age (midpt)	±	$^{87}Sr/^{86}Sr$ (err = 0.00001)
Algal tufas from east side of Winnemucca Lake Basin													
WDL89 5B-1	2–3 mm white	1205	10 8535	50	8635	20	9542–9561	67	9538–9631	98	9550	10	
	crust		10 8732	80	8800	25	9766–9898	100	9696–9917	99	9830	70	0.70589
WDL89 5B-2	3-mm stromatolite	1205	10 8536	50	10 030	20	11 404–11 459	33	11 393–11 641	94	11 430	30	
	layer		10 8733	80	10 080	25	11 611–11 754	97	11 593–11 811	79	11 680	70	0.70604
WDL89 5B-3	1-mm white layer	1205	10 8537	50	9770	20	11 197–11 220	100	11 184–11 232	100	11 210	10	
			10 8734	80	9990	25	11 327–11 409	52	11 303–11 507	70	11 370	40	
WDL89 5B-4	1-mm stromatolite	1205	10 8538	50	10 280	25	12 004–12 008	100	11 970–12 140	100	12 050	40	0.70604
	layer		10 8735	80	10 380	25	12 270–12 379	61	12 105–12 390	100	12 320	50	
WDL89 5B-5	2–4 mm gray layer	1205	10 8539	50	10 370	25	12 132–12 221	50	12 243–12 387	51	12 180	40	0.70622
WDL89 5C-1	1-mm white crust	1205	108 548	20	8505	20	9498–9527	100	9484–9533	100	9510	10	
			108 549	40	8565	25	9530–9543	100	9516–9550	96	9540	10	
			108 540	50	8630	25	9540–9562	65	9535–9633	96	9550	10	
			108 551	60	8680	20	9556–9630	92	9551–9680	100	9590	40	
			108 736	80	8700	20	9598–9680	95	9557–9696	100	9640	40	
			108 550	80	8985	25	10 174–10 208	100	10 153–10 230	98	10 190	20	
WDL89 5C-6	4–6 mm stromatolite	1205	108 542	50	10 000	25	11 429–11 495	36	11 315–11 616	100	11 460	30	
	layer		108 738	80	10 145	25	11 756–11 828	55	11 704–11 849	55	11 790	40	
WDL89 5C-5	2–4 mm gray layer	1205	108 541	50	10 570	30	12 528–12 586	75	12 517–12 622	68	12 580	30	
			108 737	80	10 645	30	12 558–12 619	100	12 545–12 667	100	12 590	30	0.70623
Tufa coatings from west side of Winnemucca Lake Basin (petroglyph site)													
WDL12-1	Abraded white crust	1206	109 220	80	7900	15	8666–8717	68	8627–8770	98	8690	30	
WDL12-4	Abraded white crust	1206	109 221	80	8785	15	9736–9797	53	9703–9893	100	9770	30	0.70616
WDL12-2	Abraded white crust	1204	109 222	80	8860	15	10 063–10 123	60	10 052–10 154	53	10 090	30	
WDL12-3	Abraded white crust	1204	109 223	80	9075	15	10 227–10 240	100	10 215–10 247	99	10 230	10	0.70621
WDL12-5A	Abraded white crust	1203	109 224	80	8890	15	9985–10 045	44	9915–10 097	78	10 020	30	
WDL12-5B	Pieces of white crust	1203	109 225	80	8920	15	9948–9989	46	9923–9996	41	9970	20	0.70623
WDL12-6B	Carbonate below crust	1203	109 226	80	10 000	15	11 432–11 493	37	11 329–11 503	64	11 460	30	0.70606
							11 550–11 601	37			11 570	30	

Abraded white crust refers to a carbonate coating that was sampled with a dremel grinding tool. Area refers to the relative area under the probability curve. Leach to the amount of carbonate removed prior to ^{14}C analysis refers.

branching tufas are essentially the same as those of dense tufas formed during the Lahontan highstand (Table S1, Fig. 4), indicating that the petroglyphs above the carbonate crust were carved into deep-water branching tufas that formed prior to 14.8 ka.

3.3. Age of the carbonate that coats the petroglyphs

To provide a minimum age for carving of the low-elevation (1202–1206 m) petroglyphs, we dated the carbonate crust that coats the petroglyphs (Fig. 3). The six carbonate-crust samples from the petroglyph site (WDL12) exhibited an age range of 10.23–9.77 ka with one outlier at 8.69 ka (Table 1). As the sample abrasion process did not always reach the inner (oldest) part of the carbonate crust, we conclude that initial deposition of the carbonate crust occurred at 10.2 ka and continued until 9.8 ka, a conjecture consistent with the TIC data discussed in Section 3.5, which indicates that lake level was constrained by overflow at 1207 m until ~9.3 ± 0.1 ka. We, therefore, conclude that the petroglyphs were carved sometime between 14.8 and 10.2 ka.

3.4. Time of deposition of the algal tufas

We also dated individual layers within algal tufas (Fig. 5B and D) from the same approximate elevation (1205 m) on the eastern side of the Winnemucca Lake subbasin (Table 1) in order to establish discrete times during which the lake occupying the Pyramid and Winnemucca lake subbasins was spilling across Emerson Pass. Substantial deposition of carbonate occurs when the surface elevation of a lake is stabilized by spill to an adjacent subbasin. $CaCO_3$, which exhibits retrograde solubility, will precipitate in the warm shallow water immediately below the spill elevation; hence the observed preferential deposition of carbonate between 1202 and 1206 m. Three pieces of this carbonate tufa (WDL89-5), not including its carbonate crust, had been previously shown to have dates ranging from 12.5 to 11.3 ka (Supplementary Table 1).

After leaching, the carbonate crusts coating the WDL89 5B-1 and 5C-1 samples produced calibrated ages of 10.2, 9.83, and 9.64 ka (Table 1). Radiocarbon analyses of the dense carbonate layers within the two WDL89-5 samples indicated a calibrated age range of 12.59–11.43 ka (Table 1), implying that the lake occupying the two subbasins had been at or near the Emerson Pass spill point (1207 m) during much of that time interval. The fact that the $^{87}Sr/^{86}Sr$ values and age ranges of the algal tufas and laminated carbonates are almost identical (Fig. 4) supports the existence of a relatively deep and freshwater lake in the Pyramid and Winnemucca subbasins much of the time between 12.8 and 11.3 ka.

3.5. TIC and the continuous record of spill from the Pyramid–Winnemucca Lake complex

Although highly informative, the tufa data are discontinuous in time and do not allow us to determine how continuous was the lake's occupation of the 1207-m spill point. This is critical because, during times of spill across Emerson Pass, the base of the tufa mound was under water and was, therefore, not accessible for the carving of petroglyphs. To address this question, we plotted the continuous set of TIC concentrations in sediment core PLC97-3 for the interval 17.0 to ~9.5 ka (Fig. 4). In doing this we implemented two age models for PLC97-3. The uppermost TIC record in Fig. 4 relies on the age model depicted in Fig. 5A and the lower TIC record in Fig. 4 relies on the age model depicted in Fig. 5B. The striking difference in the two TIC records between 11.5 and 10.5 ka (Fig. 4) attests to the sensitivity of the fit to the PSV ages in the upper part (<2.2 m) of PLC97-3 when sedimentation rates were extremely low.

When a lake increases in volume or overflows to an adjacent basin, the concentrations of dissolved Ca^2 and CO_3^{2-} decrease and, therefore, the frequency and amount of $CaCO_3$ precipitated also decreases. Thus, the amount of TIC recorded in lake sediment decreases during wet periods. On the other hand, when a lake exists in a hydrologically closed state or decreases in size, the relative concentration of TIC increases in its sediments (see, e.g., Benson et al., 2012). The continuous TIC records in Fig. 4 indicate that Lake Lahontan fell from its highstand level at ~15 ka reaching a level of ~1165 m at 14.5 ka and then remained hydrologically closed at low levels until ~13.3 ka. At that time, it rose to its 1207 m spill point and remained there for much of the time between 13.2 and ~9.5 ka.

The TIC records resulting from the two age models indicate that the base of the petroglyph site was subaerially exposed between 15.0 and 13.2 ka and was subject to the carving of petroglyphs. However, the TIC records resulting from the two age models indicate different times of possible subaerial exposure after 13.2 ka. One age model (Fig. 5A) indicates that the base of site WDL12 was subaerially exposed between 11.3 and 10.5 ka and the other age model (Fig. 5B) indicates that the base of site WDL12 was subaerially exposed between 11.5 and 11.1 ka.

3.6. What underlies the carbonate crust at site WDL12?

Unfortunately, we were not permitted to explore the layering history directly associated with a carbonate encrusted petroglyph. Therefore, we do not know whether some or all of the dense layers present in the WDL89-5 samples also are present beneath the carbonate crust at the petroglyph site. We also do not know whether petroglyph carving pre- or post-dated the deposition of such layers. We were allowed to collect a shallow (10-mm-long) core (WDL12-6) from a nearby carbonate-encrusted boulder that lacked petroglyphs (Fig. 3C). The core penetrated a dense carbonate layer (WDL12-6B) that underlies the carbonate crust at that locality. The dense layer had a date of ~11.5 ka (Table 1), which is consistent with the date (11.7 ka) of the youngest algal stromatolite layer in WDL89 5B-2. The $^{87}Sr/^{86}Sr$ ratios of WDL12-6B and WDL89 5B-2 are also nearly identical, suggesting the dense carbonate layer precipitated at the same time from the same body of water. This implies that some of the carbonate deposited on the east side of the Winnemucca Lake subbasin was also deposited on the base of the carved tufa mound on the west side of the subbasin. However, we were unable to determine whether this carbonate had coated the base of the tufa mound prior to or after the petroglyphs were carved. If prior to, it would indicate that petroglyph carving occurred before 11.5 ka, which would imply that the petroglyphs were carved sometime between 14.8 and 13. ka.

3.7. Implications of the strontium-isotope record

As Lake Lahontan fell from its highstand elevation, input of radiogenic $^{87}Sr/^{86}Sr$ to the Pyramid and Winnemucca lake subbasins from the Humboldt River ceased (Benson and Peterman, 1995). Therefore, the $^{87}Sr/^{86}Sr$ of water in the latter two subbasins decreased due to the sole input of Truckee River water which contains Sr with a relatively low $^{87}Sr/^{86}Sr$ ratio (Supplementary Table 1). The decrease in $^{87}Sr/^{86}Sr$ (0.70622–0.70589) of the algal tufa layers with decreasing age (12.18–9.83 ka) (Table 1) supports the concept that the algal layers were deposited from lake water that was being diluted with Truckee River water as the lake overflowed the Emerson Pass Sill. This finding also is consistent with the presence of freshwater diatoms in the upper two algal tufa layers which imply the existence of a spilling lake in the Winnemucca Lake subbasin.

3.8. Ages of archaic materials found in the Lahontan Basin

Calibrated ages of Lahontan Basin Archaic materials (human bone, hair, textiles, fishing line) listed in Supplementary Table 2 are plotted in Fig. 4. Textiles from the Winnemucca Lake subbasin date as early as 10.68 ka (Hattori, 1982). These materials range in age from 11.0 to 10.4 ka, and fall within the 11.2–10.3 ka tufa gap. The two age models (Fig. 5) indicate that the base of site WDL12 was subaerially exposed between 11.3 and 10.5 ka or between 11.5 and 11.1 ka (Fig. 4). Thus, the TIC record associated with the first age model is consistent with the tufa record and suggests that Lahontan Basin Native Americans could have been responsible for the creation of petroglyphs found at the base of the collapsed tufa mound. The TIC record associated with the second age model (Fig. 5B) suggests that there existed a very narrow window between 13.2 and ~9.5 ka when the petroglyphs could have been carved and that this window opened just prior to evidence for early Archaic Native Americans in the Lahontan Basin. We cannot rule out the possibility that petroglyph carving occurred between 14.8 and 12.8 ka when the lake in the Pyramid Lake subbasin was at low levels and Winnemucca Lake had desiccated. Paleoindians had reached the Great Basin on or before 14.4 ka (Gilbert et al., 2008) and if they also occupied the Lahontan Basin at that time, it is conceivable they witnessed the desiccation of Winnemucca Lake and created the petroglyphs at archaeological site 26Wa3329.

3.9. Comparison of the Winnemucca Lake petroglyph site with the Long Lake petroglyph site

The Long Lake petroglyph site is comprised of dozens of petroglyph panels pecked, painted, and deeply carved into ledges and boulders exposed along a 4-km-long, low, basalt rim overlooking ephemeral Long Lake above Warner Valley, Lake County, Oregon (Cannon and Ricks, 1986). Some of these petroglyph panels are very distinctive, and one of these panels (Fig. 8) was buried by the 7.63 ka Mount Mazama tephra. Until publication of this paper, this panel represented the oldest and best dated early archaic petroglyph panel in the Great Basin. Cannon and Ricks (1986) named the distinctive style of carving displayed at the Long Lake site "Great Basin Carved Abstract". In addition to the buried panel, other panels at Long Lake share attributes with panels and petroglyphs at the Winnemucca Lake site (see, e.g., Figs. 2 and 9). The dominate projectile points at Long Lake are Great Basin stemmed and Humboldt Concave base types (Cannon and Ricks, 2008).

Fig. 8. Petroglyph panel at Long Lake, Oregon, displaying deeply incised carvings in basalt. Mount Mazama tephra originally covered lighter area on base of panel. Black vertical bar = 15 cm.

Fig. 9. Petroglyph panel at Long Lake, Oregon located ~1.2 km north of panel in Fig. 8. Note motifs comprised of short vertical lines in upper part of panel and stacked chevron variants in lower left of panel. Black vertical bar = 15 cm.

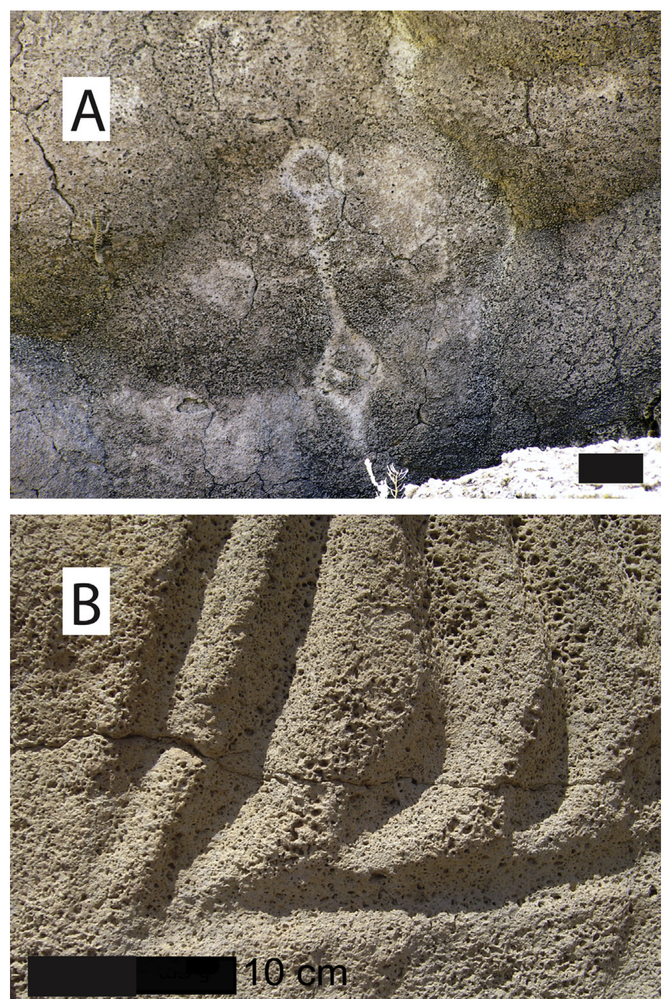

Fig. 10. A. Relatively young petroglyph from the southern end of the Winnemucca Lake subbasin. Note shallow line depth. B. Deeply carved lines in tufa at Winnemucca Lake petroglyph site. Black bars are 10 cm in length.

Fig. 11. Bisected chevron design (tree form) at the Winnemucca Lake petroglyph site. The tree form is 70 cm tall. Note additional tree form in shadow at upper left of figure.

There are distinctive design features common to both the Winnemucca Lake and Long Lake petroglyphs which also appear elsewhere in the Great Basin (Connick and Connick, 1992; Heizer and Baumhoff, 1962; Swartz, 1978). These include the following features: relatively deep carved lines; dominance of linear, curved, and circular geometric designs; symmetrical groupings of cupules on vertical faces; and relatively dense grouping of elements. Although the tufa at Winnemucca Lake is relatively soft when compared to Long Lake basalt, the vast majority of petroglyphs carved into other tufa formations in the Winnemucca and Pyramid lake subbasins are much shallower in depth than those at site 26Wa3329 (Fig. 10A and B) (Connick and Connick, 1992). Most petroglyphs assigned to the middle archaic-historic time sequence were formed by relatively shallow (<5-mm depth) carving (Heizer and Baumhoff, 1962).

Specific, distinctive design elements occur at both the Long Lake and Winnemucca Lake sites. Among these elements are “tree-form” designs comprised of series of evenly spaced, vertically oriented (sometimes arched) chevrons bisected by a vertical line (Figs. 9 and 11). Another distinctive element, with variants, that occur at both sites are deeply incised petroglyph panels with short linear sections containing vertical, parallel lines (Figs. 9 and 12). At the Winnemucca and Long lake sites, cupules are utilized as elements in the creation of patterned designs on vertical faces (Figs. 13 and 14). Cupules are shallow mortar-like pits that most commonly occur on horizontally oriented surfaces. Sometimes the pits are associated with interconnecting troughs or grooves. Heizer and Baumhoff (1962) classify the latter association as the pit and groove rock art style that they consider to be an older Great Basin petroglyph type. We consider the Winnemucca Lake petroglyphs to

Fig. 13. Cupules on the vertical face of a tufa boulder at the Winnemucca Lake petroglyph site. Cupules can also be seen in Fig. 2. Vertical black bar is 50 cm in length.

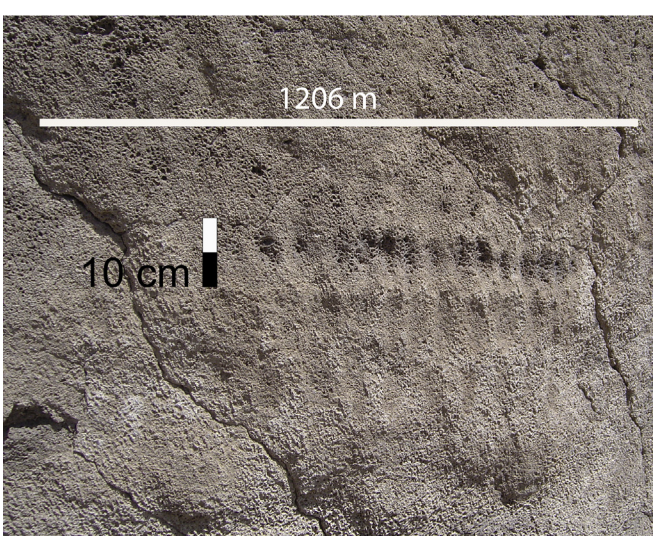

Fig. 12. Stacked set of short vertical lines at the Winnemucca Lake petroglyph site. The carbonate coating that reached 1206 m is shown as the white patchy surface in the lower half of the figure.

Fig. 14. Heavily patinated and eroded cupules on a vertical basalt face at Long Lake, Oregon. Vertical black bar is 20 cm in length.

represent an early archaic style characterized by distinctive design elements and motifs created using deeply carved lines and cupules. It is possibly a variant of Cannon and Ricks' (1986) Great Basin Carved Abstract style.

4. Conclusions

Radiocarbon dating was used to directly bracket the time interval during which Native Americans carved an array of geometric forms into a prominent tufa mound (site 26Wa3329) on the western side of the Winnemucca Lake subbasin. The carbonate into which the petroglyphs were carved has a minimum date of 14.8 ka and the carbonate crust that coats petroglyphs near the base of the tufa mound has a maximum date of 10.2 ka. Three other data sources were used to indirectly determine when water level in the Pyramid and Winnemucca lake subbasins was held at 1207 m by overflow across the Emerson Pass Sill. When the coalesced lake system was at this level, the base of the tufa mound was not accessible for carving. The indirect data sources include: the TIC record from a lake-sediment core (PLC97-3), tufa-based data on the $^{87}Sr/^{86}Sr$ evolution of lake water, and ^{14}C ages of carbonate layers in an algal tufa deposited at 1205 m on the eastern side of the Winnemucca Lake subbasin. The indirect data sets indicate that the base of the collapsed tufa mound was subaerially exposed between 14.8 and 13.2 ka and between 11.3 and 10.5 ka or between 11.5 and 11.1 ka (depending on which age–depth model is adopted). Low lake levels in the tufa-based ^{14}C record support the 14.8–13.2 ka and 11.3–10.5 ka intervals, and Native American artifacts found in the Lahontan Basin also date to the latter time interval. However, these data do not rule out the possibility that petroglyph carving occurred between 14.8 and $\sim$13 ka when Pyramid Lake was relatively shallow and Winnemucca Lake had desiccated.

The carbonate crust coating both the base of the petroglyph site and algal tufa on the opposite of the subbasin indicate the persistence of a large body of water in the Lahontan Basin until $\geq$9.2 ka. The influence of such an intense and previously unrecorded post-Younger Dryas wet event in the western Great Basin on prehistoric Native American cultures remains to be determined.

The 26Wa3329 petroglyphs share a number of attributes with the Long Lake, Oregon, petroglyphs dating to at least the early archaic period. These include deeply carved lines and cupules in geometric motifs shared between the two regional sites. Deeply carved, specific motifs that are common to both Winnemucca Lake and Long Lake sites are also found elsewhere in the western Great Basin from Oregon to southeastern California.

Acknowledgments

Support for this project was provided by the National Research Program of the U.S. Geological Survey. The authors thank the Pyramid Lake Tribal Council for allowing access to the Winnemucca Lake subbasin petroglyph site. Emily Verplanck at the University of Colorado performed the strontium-isotope analyses. We also thank Bill Cannon, Lakeview District BLM, and Sue Ann Monteleone, Nevada State Museum, for their technical assistance. We thank Scott Starratt of the U.S. Geological Survey who performed the diatom analyses.

Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.jas.2013.06.022.

References

Benson, L., 1994. Carbonate deposition, Pyramid Lake subbasin, Nevada: 1. sequence of formation and elevational distribution of carbonate deposits (tufas). Palaeogeography Palaeoclimatology Palaeoecology 109, 55–87.

Benson, L., Kashgarian, M., Rye, R., Lund, S., Paillet, F., Smoot, J., Kester, C., Mensing, S., Meko, D., Lindström, S., 2002. Holocene multidecadal and multicentennial droughts affecting Northern California and Nevada. Quaternary Science Reviews 21, 659–682.

Benson, L., Peterman, Z., 1995. Carbonate deposition, Pyramid lake subbasin, Nevada: 3. The use of ^{87}Sr values in carbonate deposits (tufas) to determine the hydrologic state of paleolake systems. Palaeogeography Palaeoclimatology Palaeoecology 119, 201–213.

Benson, L., Smoot, J.P., Lund, S.P., Mensing, S.A., Foit Jr., F.F., Rye, R.O., 2012. Insights from a synthesis of old and new climate-proxy data from the Pyramid and Winnemucca lake basins for the period 48–11.5 cal ka. Quaternary International. http://dx.doi.org/10.1016/j.quaint.2012.02.040.

Cannon, W., Ricks, M.J., 1986. The Lake County rock art inventory: implications for prehistoric settlement and land use patterns. In: Ames, K.M. (Ed.), 1986. Contributions to the Archaeology of Oregon 1983–1986, vol. 3, pp. 1–23. Association of Oregon Archaeologists Occasional Papers.

Cannon, W.J., Ricks, M.J., 2008. Ethnobotanical Clues to Rock Art Placement. In: Paper Presented at the 31st Great Basin Anthropological Conference, Portland, OR.

Connick, R.E., Connick, F., 1992. The hitherto unrecognized importance of Nevada site 26Wa3329: a monumental site with southwestern connections. In: Hedges, K. (Ed.), Rock Art Papers, San Diego Museum Papers, vol. 28(9), pp. 73–99.

Dillehay, T.D., Ramirez, C., Pino, M., Collins, M.B., Rossen, J., Pino-Navarro, J.D., 2008. Monte Verde: seaweed, food, medicine, and the peopling of South America. Science 320, 784–786.

Faith, J.T., Surovell, T.A., 2009. Synchronous extinction of North America's Pleistocene mammals. Proceedings of the National Academy of Sciences 106, 20641–20645.

Gilbert, M.T.P., Jenkins, D.L., Götherstrom, A., Naveran, N., Sanchez, J.J., Hofreiter, M., Thomsen, P.F., Binladen, J., Higham, T.F.G., Yohe II, R.M., Parr, R., Cummings, L. Scott, Willerslev, E., 2008. DNA from pre-Clovis human coprolites in Oregon, North America. Science 320, 786–788.

Grayson, D.K., Meltzer, D.J., 2003. A requiem for North American overkill. Journal of Archaeological Science 30, 585–593.

Hattori, E.M., 1982. The Archaeology of Falcon Hill. In: Anthropological Paper No. 18. Nevada State Museum, Winnemucca Lake, Washoe County, Nevada.

Heizer, R.F., Baumhoff, M.A., 1962. Prehistoric Rock Art of Nevada and Eastern California. University of California Press, Berkeley.

Lund, S.P., 1996. A comparison of Holocene paleomagnetic secular variation records from North America. Journal of Geophysical Research 101, 8007–8024.

Lund, S.P., Acton, G.D., Clement, B., Okada, M., Williams, T., 2001a. Paleomagnetic records of Stage 3 excursions from ODP Leg 172 sediments. In: Keigwin, L.D., Rio, D., Acton, G.D., Arnold, A.E. (Eds.), 2001a. Proceedings of the Ocean Drilling Project, Scientific Results, vol. 172. (Chapter 10).

Lund, S.P., Acton, G.D., Clement, B., Okada, M., Williams, T., 2001b. Brunhes Epoch magnetic field excursions recorded in ODP Leg 172 sediments. In: Keigwin, L.D., Rio, D., Acton, G.D., Arnold, A.E. (Eds.), 2001b. Proceedings of the Ocean Drilling Project, Scientific Results, vol. 172. (Chapter 11).

Mifflin, M.D., Wheat, M.M., 1971. Isostatic rebound in the Lahontan Basin, northwestern Great Basin. In: Geological Society of America Annual Meeting, p. 647.

Neves, W.A., Araujo, A.G.M., Bernardo, D.V., Kipnis, R., Feathers, J.K., 2012. Rock art at the Pleistocene/Holocene boundary in eastern South America. PLoS ONE 7 (2), e32228. http://dx.doi.org/10.1371/journal.pone.0032228.

Overstreet, D.F., Stafford Jr., T.W., 1997. Additions to a revised chronology for cultural and non-cultural mammoth and mastodon fossils in the southwestern Lake Michigan Basin. Current Research in the Pleistocene 14, 70–71.

Purdy, B.A., Jones, K.S., Bourne, G., Hulbert Jr., R.C., 2011. Earliest art in the Americas: incised imager of a proboscidean on a mineralized extinct animal bone from Vero Beach, Florida. Journal of Archaeological Science 38, 2908–2913.

Stuiver, M., Reimer, P.J., 1993. Extended ^{14}C data base and revised CALIB 3.0 calibration program. Radiocarbon 35, 215–230.

Swartz Jr., B.K., 1978. Klamath Basin Petroglyphs. In: Anthropological Papers No. 12. Revised and Abridged Ballena Press.

Zdanowicz, C.M., Zielinski, G.A., Germani, M.S., 1999. Mount Mazama eruption: calendrical age verified and atmospheric impact assessed. Geology 27, 621–624.