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

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**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 9,800 calibrated years B.P. (ka) coats petroglyphs at the base of the mound between elevations of 1,202 and 1,206 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 1,205 m, as well as a sediment-core-based total inorganic carbon record for the period 17.0 to 9.5 ka indicate that water level in the Winnemucca Lake subbasin was constrained by spill over the Emerson Pass Sill (1,207 m) for most of the time between 12.9 and 9.2 ka. These and other data indicate that the lake in the Winnemucca Lake subbasin fell beneath 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 14C record supports decreased lake levels between 14.8 to 13.2 ka and 11.3 to 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.

**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 ~13,000 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...
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...
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 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 (14C) 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.

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).

The elevation (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.
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% 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
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 14C age of samples from their times of deposition

All 15 carbonate samples were 14C 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, 14C dates on lacustrine carbonates are subject to a “reservoir effect”, wherein, the presence of excess dead carbon can shift the apparent 14C 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 CO2, 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...
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-carbonate-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 (CO₂) 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 they 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 14C 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 14C 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 14C ages of tufas deposited during spill over the Emerson Pass Sill should not be expected to have been offset by a substantial reservoir effect.

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 CaCO₃, 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 14C 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 14C analysis, except for WDL89 5B-5 for which insufficient material remained.

It should be noted that the 14C 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 crust and suggests that the resulting 14C 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 87Sr/86Sr analysis. The 87Sr/86Sr analyses were done at the University of Colorado heavy-isotopes laboratory. The error in the 87Sr/86Sr analyses was <1 unit in the fifth decimal place. Previous 87Sr/86Sr 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 14C-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 87Sr/86Sr 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.

<table>
<thead>
<tr>
<th>Sample name</th>
<th>Layer type</th>
<th>Ele. (m)</th>
<th>UCIAMS no.</th>
<th>Leach (%)</th>
<th>$^{14}$C Age (BP)</th>
<th>± 1σ range</th>
<th>Area (%)</th>
<th>Calib age 1σ range</th>
<th>± 2σ range</th>
<th>Area (%)</th>
<th>Calib age 2σ range</th>
<th>± 3σ range</th>
<th>$^{87}$Sr/$^{86}$Sr (err = 0.00001)</th>
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<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>WDL89 5B-1</td>
<td>2–3 mm white crust</td>
<td>1205</td>
<td>10 8535</td>
<td>50</td>
<td>8635</td>
<td>20</td>
<td>9542–9561</td>
<td>67</td>
<td>9538–9631</td>
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<td>9550</td>
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<td>10 8536</td>
<td>50</td>
<td>10 030</td>
<td>20</td>
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<td>33</td>
<td>11 391–11 641</td>
<td>94</td>
<td>11 430</td>
<td>30</td>
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<td>10 8537</td>
<td>50</td>
<td>9770</td>
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<td>11 184–11 232</td>
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<td>9990</td>
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<td>11 327–11 409</td>
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<td>10 280</td>
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<td>12 004–12 008</td>
<td>100</td>
<td>11 970–12 140</td>
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<td>12 050</td>
<td>40</td>
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<td>20</td>
<td>8505</td>
<td>20</td>
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<td>40</td>
<td>8565</td>
<td>25</td>
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<td>11 790</td>
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<td>Tufa coatings from west side of Winnemucca Lake Basin (petroglyph site)</td>
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<td>10 052–10 154</td>
<td>53</td>
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<td>10 000</td>
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<td>37</td>
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</table>

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. CaCO₃, 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 5C1-1 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 ⁸⁷Sr/⁸⁶Sr 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 Ca²⁺ and CO₃⁻ decrease and, therefore, the frequency and amount of CaCO₃ 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 ⁸⁷Sr/⁸⁶Sr 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 ⁸⁷Sr/⁸⁶Sr to the Pyramid and Winnemucca lake subbasins from the Humboldt River ceased (Benson and Peterman, 1995). Therefore, the ⁸⁷Sr/⁸⁶Sr of water in the latter two subbasins decreased due to the sole input of Truckee River water which contains Sr with a relatively low ⁸⁷Sr/⁸⁶Sr ratio (Supplementary Table 1). The decrease in ⁸⁷Sr/⁸⁶Sr (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 20Wa3329.

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).
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 (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

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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.

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. 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. 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 87Sr/86Sr evolution of lake water, and 14C 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 14C 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 ~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 ≥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.

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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