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2006

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Benson, L.V.; Hattori, E.M.; Taylor, H. E.; Poulson, S.R.; and Jolie, E.A., "Isotope sourcing of prehistoric willow and tule textiles recovered from western Great Basin rock shelters and caves e proof of concept" (2006). *USGS Staff -- Published Research*. 751.  
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# Isotope sourcing of prehistoric willow and tule textiles recovered from western Great Basin rock shelters and caves – proof of concept

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Received 1 December 2005; received in revised form 21 February 2006; accepted 22 February 2006

## Abstract

Isotope and trace-metal analyses were used to determine the origin of plants used to manufacture prehistoric textiles (basketry and matting) from archaeological sites in the western Great Basin. Research focused on strontium ( $^{87}\text{Sr}/^{86}\text{Sr}$ ) and oxygen ( $^{18}\text{O}/^{16}\text{O}$ ) isotope ratios of willow (*Salix* sp.) and tule (*Schoenoplectus* sp.), the dominant raw materials in Great Basin textiles. The oxygen-isotope data indicated that the willow and tule used to produce the textiles were harvested from the banks of rivers or in marshes characterized by flowing water and not from lakes or sinks. The strontium-isotope data were useful in showing which plants came from the Humboldt River and which came from rivers headed in the Sierra Nevada.

Published by Elsevier Ltd.

**Keywords:** Lahontan Basin; Lovelock Wickerware; Textiles; Isotopes

## 1. Introduction

This paper assesses the potential of using strontium and oxygen isotopes and trace metals to determine the sources of willow and tule used in archaeological textiles (basketry and matting) recovered from the Lake Lahontan Basin and Dixie Valley, Nevada.<sup>1</sup> Our study focuses on basketry associated with the western Great Basin's Lovelock archaeological culture which persisted from ca. 4000 to 600  $^{14}\text{C}$  years (yr) before present (B.P.) (2500 BC–AD 1300).<sup>2</sup>

### 1.1. The Lovelock archaeological culture and its textiles

The Lovelock archaeological culture was initially based on distinctive artifact types recovered from rich cultural deposits excavated by Loud and Harrington [21] at Lovelock Cave, Nevada, and it is characterized by an intensive adaptation to lake–marsh resources. Lovelock material culture includes the following diagnostic artifact types: large, shaped mortars with conical grinding areas and biconical pestles; Lovelock Wickerware burden baskets; coiled winnowing and parching trays; coiled water bottles; finely woven, feathered coiled basketry caps; L-shaped, scapula awls; tule, duck decoys; and zoomorphic figurines [15]. Subtle differences in material culture lead some to suggest a level of cultural differentiation that correlates with western Nevada hydrographic subbasins across which the Lovelock peoples were distributed. Descriptive data on Lovelock Wickerware and coiled basketry, among other artifact classes, strongly reflect this variability (e.g., [16]; Jolie, University of Nevada, M.A. thesis, 2004). In fact, the genesis of this research relates to the differential distribution

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<sup>1</sup> According to the M.A. thesis of E. Jolie (Coiled Basketry from Charlie Brown Cave, Nevada, University of Nevada, 2004), the provenience of the “Dixie Valley” Lovelock Wickerware has not been firmly established. It was chosen because the collection contained large fragments of Lovelock Wickerware and tule matting suitable for testing the method.

<sup>2</sup> All radiocarbon dates in this paper have been calibrated (cal) using CALIB 5.01 [25]. In all cases, the center point of the highest probability range was used.

of a Lovelock archaeological culture basketry type, Lovelock Wickerware.

Lovelock Wickerware (Fig. 1) is a unique plain weave or plaiting. Plain weave is typically a simple weave with elements passing over and under each other without engagement. The “warp” and “weft” are usually identical. Lovelock Wickerware, however, employs a semi-flexible, paired weft and a rigid warp rod [2]. The weft comprises peeled and sized willow strips. These weft strips are usually stacked or, rarely, laid side by side. The warp is a single, peeled willow rod that is only paired to form the basket’s rim or finish.

There are relatively few direct dates on Lovelock Wickerware, but they range from  $3270 \pm 180$  to  $580 \pm 100$   $^{14}\text{C}$  yr B.P. ( $1573 \pm 200$  BC to AD  $1336 \pm 38$ ) [27]. The  $580 \pm 100$   $^{14}\text{C}$  date is a single, composite date derived from three samples; thus, one of the three Wickerware samples is most likely younger than the composite date. Lovelock Wickerware was not present in the ethnographic (historic) period.

Lovelock Wickerware basketry is an important hallmark of the Lovelock archaeological culture. More than 1000 fragments of Lovelock Wickerware were recovered from Lovelock Cave, Nevada (Fig. 2B), and the excavators of that site concluded that, “...all or nearly all wicker basketry constitutes fragments of conical burden baskets” [21]. Closely woven, conical burden baskets were general, utilitarian containers used by ethnographic, Great Basin Native American groups throughout the year in their subsistence cycle. Lovelock Wickerware probably functioned similarly. However, these ethnographic baskets differ significantly in that they are manufactured using distinctive twined weaving techniques (single weft elements twisted around alternating, paired warps).

Lovelock Wickerware is only known from the Humboldt Sink, Pyramid and Winnemucca lake basins, the Carson Desert, and, possibly, Dixie Valley in western Nevada. Although Humboldt Sink sites and Pyramid and Winnemucca lake-basin sites yielded significant quantities of Lovelock Wickerware, Carson Desert sites have yielded fewer than five examples of this textile, despite the excavation of several, large artifact assemblages



Fig. 1. A sample of Lovelock Wickerware from Lovelock Cave, Nevada.

from the Lovelock archaeological culture interval. Determination of the source of materials used in fabricating Lovelock Wickerware may help us understand Lovelock resource-procurement strategies and segmentation of the culture.

Obviously, there was not a strong tradition of Lovelock Wickerware production in the Carson Desert. Were the few examples of Wickerware represented in Carson Desert sites traded into that area from neighboring groups to the north or west? It seems reasonable that if the raw, plant material for Wickerware was grown outside the Carson Desert, then an important attribute of the Lovelock archaeological culture was essentially missing from the Carson Desert. Conversely, if Carson Desert Wickerware was made from plants grown within the Carson Desert, then why was it produced in such low quantities?

To begin exploring this anomalous distribution we attempted isotope and trace-metal sourcing of willow used in Lovelock Wickerware production. Willow also is the dominant raw material for Lovelock coiled basketry. We hoped that the major Sierran drainages (Carson, Truckee, and Walker rivers) and the Humboldt River, all of which terminate in the Lahontan Basin would each have a distinctive chemical signature that was imparted to plants growing in and along these surface-water systems. Great Basin willows (*Salix* sp.) are shrubs that grow in mesic habitats along stream banks or, less commonly, within sheltered quiet-water environments in lake basins and marshes. Given the salinity intolerance of common sandbar/coyote willow (*Salix exigua*), we do not expect willows to thrive along the margins of saline, terminal drainage basins.

We also included tule (*Schoenoplectus* cf. *acutus*) to test its usefulness in isotope and trace-metal sourcing. Tule is a wetland emergent plant dependent upon a saturated, oxygenated root zone. In contrast to Lovelock Wickerware, tule basketry and matting employ twined weaving (Fig. 3). Typically, a pair of tule weft elements are twined or twisted around a stationary, semi-flexible tule warp. Basketry containers, flat mats and bags were woven from tule. Open-twined, tule warp and weft mat production first appears at  $9460 \pm 60$   $^{14}\text{C}$  yr B.P. ( $10,700 +90/-100$  cal B.P.) [12] and continues throughout Lovelock times into the ethnographic period. The tule samples analyzed in this study have not been  $^{14}\text{C}$  dated, and we cannot presently assign them to the Lovelock period. They do, however, exhibit strong stylistic and technological affinities with Lovelock textiles which suggest our chronological placement is reasonable. By ethnographic times there are notable changes in primary technological features that distinguish Lovelock textiles from those produced historically [11].

## 1.2. Strontium (Sr) isotopes

Sr-isotope ratios ( $^{87}\text{Sr}/^{86}\text{Sr}$ ) have recently been used to determine where trees used in construction of Chaco Canyon, New Mexico, great houses were harvested [10,23] and where maize found in Pueblo Bonito, Chaco Canyon was grown [7,9]. There are two Sr isotopes of interest –  $^{87}\text{Sr}$  and  $^{86}\text{Sr}$ .  $^{86}\text{Sr}$  is a stable isotope, whereas  $^{87}\text{Sr}$  is a stable radiogenic

isotope produced by the radioactive decay of  $^{87}\text{Rb}$  with a half-life of 48.8 billion years. Thus the  $^{87}\text{Sr}/^{86}\text{Sr}$  ratio of a rock and the soil derived from it is a function of the initial  $^{87}\text{Sr}/^{86}\text{Sr}$  ratio of the rock, its age, and the amount of  $^{87}\text{Rb}$  initially present in the rock. However, the rate of production of  $^{87}\text{Sr}$  is so slow that the  $^{87}\text{Sr}/^{86}\text{Sr}$  ratio of a substance can be considered invariant over archaeological timescales.

The isotopes of Sr are nearly identical in their physical and chemical properties; therefore, measurable isotopic fractionation is not detectable during chemical and physical transformations. In terms of Sr delivery to a plant, the soil water takes on the  $^{87}\text{Sr}/^{86}\text{Sr}$  ratio of the soluble (biologically available) soil components which, in turn, is transferred unchanged to the plant.

The use of Sr isotopes to pinpoint source areas of biological materials (e.g., willow and tule) will be successful only if biologically available Sr possesses distinctive source-area signatures. With respect to the Lahontan Basin, Benson and Peterman [5] have shown that Sierran rivers (Walker, Carson, and Truckee rivers) have lower  $^{87}\text{Sr}/^{86}\text{Sr}$  ratios than the Humboldt River which drains the Ruby Mountain metamorphic complex and northeastern Nevada Paleozoic carbonates (Fig. 4). This implies that Sr isotopes should be useful in discriminating between plants that grew along the Humboldt River and Humboldt Sink and plants that grew along the

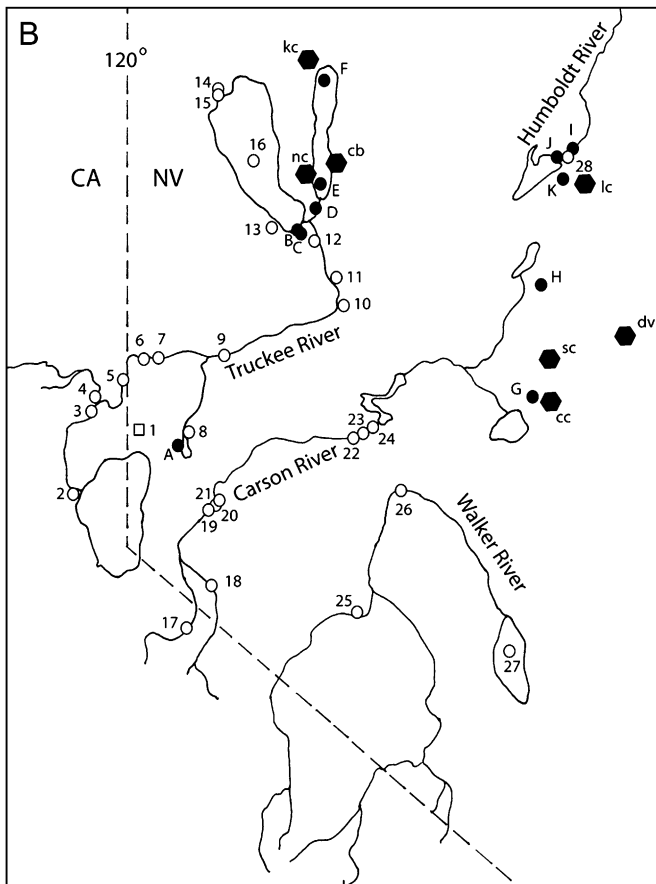
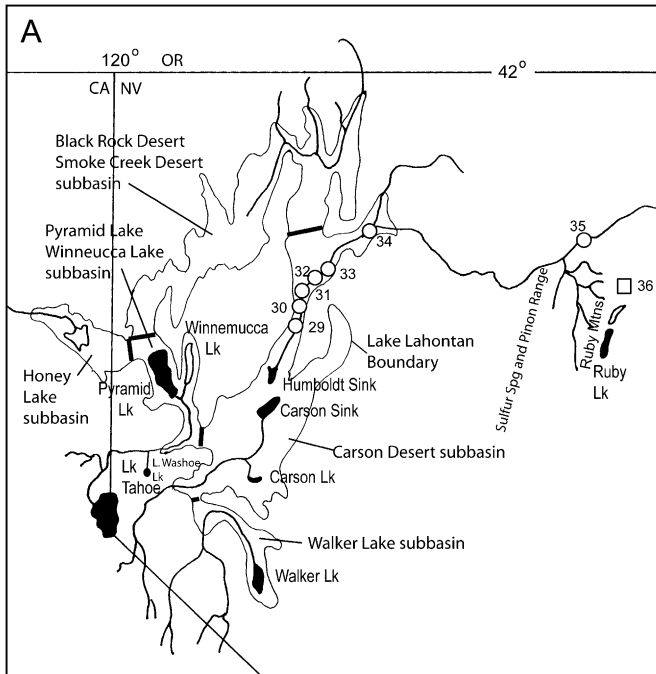


Fig. 2. Western Great Basin and Eastern Sierran sample location maps. (A) Samples from upper and middle Humboldt River surface-water system. *Water sites*: (29) Humboldt River at Rye Patch Dam [RPHR03-1], (30) Humboldt River at Old Pitt Dam [HR04-3], (31) Humboldt River at Calahan Bridge [HR04-5], (32) Humboldt River at Imlay, (33) Humboldt River at Mill City Bridge [HR04-4], (34) Humboldt River at Winnemucca [JLHRW93-1], (35) Humboldt River at Elko [HR93-1, JLHRE93-1], and (36) Ruby Valley precipitation. Sills separating subbasins are shown as thick black lines. (B) Samples from Sierran (Truckee, Carson, Walker), and lower Humboldt river surface-water systems. *Water sites*: (1) Tahoe Meadows precipitation collection site, (2) Tahoe City, (3) Truckee River above Little Truckee outlet from Boca Dam [TR03-2], (4) Little Truckee River below Boca Dam [LTR03-1], (5) Truckee River at Farad [JLTRF93-1], (6) Oxbow wetland near Truckee River [TR04-4], (7) Truckee River at Reno [TR93-1], (8) Little Washoe Lake [LWL03-1], (9) Truckee River at Lockwood Bridge [TR04-1], (10) Truckee River at Wadsworth Bridge [TR04-2], (11) Truckee River at S-S Ranch [TR04-3], (12) Truckee River at Nixon, (13) Popcorn Rocks Spring [PLPRS93-1], (14) Needles Rocks geothermal well [NW93-1], (15) Needles Rocks Springs [NS93-1, JLPLNS91-1], (16) Pyramid Lake [PL93-1, JLPL91-1], (17) West Fork of Carson River at Woodfords, (18) East Fork of Carson River at Gardnerville, (19) Mexican Ditch near Carson River [CR04-1], (20) Carson River at Carson City [CR93-1], (21) Carson River at Pinion Hills Drive [CR04-2], (22) Carson River downstream from Buckland Station [CR04-3], (23) Carson River wetland at Hercules Pond [CR04-4], (24) Carson River downstream from Hercules Pond [CR04-5], (25) West Walker River near Yerrington [JLWWR93-1], (26) Walker River at Wabuska [WR93-1], (27) Walker Lake [WL93-1], and (28) Humboldt River at bridge near Lovelock Cave and Humboldt River at spillway [HR04-1, HR04-2]. *Soil sites*: (A) west shore of Washoe Lake [WAL#1], (B) Pyramid Lake delta [PLD#1], (C) Duck Lake playa [PLP#2], (D) Mud Lake Slough [WDL#3], (E) south end of Winnemucca (Dry) Lake playa [WDL#1,#2], (F) north end of Winnemucca (Dry) Lake playa [WDL#4], (G) Carson Sink west of Hidden Cave [CSHC#1], (H) Carson Sink at Goose (Dry) Lake [CSGL#1], (I) bank of Humboldt River [HS#3], (J) playa to the northwest of Lovelock Cave [HS04-1,2], and (K) Humboldt Sink near Lovelock Cave [HS#1,#2]. *Textile sites*: (cb) Charlie Brown Cave, (lc) Lovelock Cave, (dv) approximate location of textiles thought to be from Dixie Valley, Cache Cave (cc).



Fig. 3. A sample of open-twined tulle matting from Charlie Brown Cave, Nevada.

Truckee, Carson, and Walker rivers, Pyramid Lake, Winnemucca Lake, Walker Lake and the Carson Sink (Fig. 2).

1.3. Oxygen (O) isotopes

There are three isotopes of oxygen, <sup>18</sup>O, <sup>17</sup>O and <sup>16</sup>O, with relative abundances of 0.205, 0.038, and 99.757 atom%, respectively. Oxygen-isotope (<sup>18</sup>O and <sup>16</sup>O) abundances are expressed in parts per thousand (‰ or per mil) difference from a standard. In this study Vienna Standard Mean Ocean Water (VSMOW) was used. Therefore,

$$\delta^{18}\text{O (per mil)} = \left[ \frac{\left( \frac{^{18}\text{O}}{^{16}\text{O}} \right)_x}{\left( \frac{^{18}\text{O}}{^{16}\text{O}} \right)_{\text{std}}} - 1 \right] \times 1000 \quad (1)$$

The  $\delta^{18}\text{O}$  value is a function of the temperature at which precipitation (rain or snow) condensed; i.e., the colder the temperature the more depleted (more negative) the  $\delta^{18}\text{O}$  value of the condensate. In addition, the  $\delta^{18}\text{O}$  value of precipitation gets more depleted the farther the air mass travels. This is caused by the continued fractionation of the oxygen isotopes in the air mass as rain/snow condenses from it [14]. The  $\delta^{18}\text{O}$  values of streams in the Great Basin of the western United States (U.S.) reflect, for the most part, the integrated  $\delta^{18}\text{O}$  value of snowmelt in their watersheds. Given the brief transport times of most rivers in the western U.S. (a few days to a few weeks), evaporation has little effect on their  $\delta^{18}\text{O}$  values prior to their discharge into a lake or ocean basin. However, once water reaches a lake, sink, or wetland area, evaporation preferentially removes the lighter isotopes of oxygen from the more condensed phase (water) [4]. The longer the residence time of water in a basin, the greater the degree of fractionation of the oxygen isotopes. Therefore, the  $\delta^{18}\text{O}$  value of a lake or sink increases in proportion to the residence time of water. Thus the  $\delta^{18}\text{O}$  value of plants that grow along flowing streams will have lower  $\delta^{18}\text{O}$  values than plants which grow in lakes or sinks (see, e.g., [3]).

1.4. Trace-metal fractionation

Because the <sup>87</sup>Sr/<sup>86</sup>Sr ratios of rivers emanating from the Sierra Nevada are so similar (Fig. 4), we attempted to use their

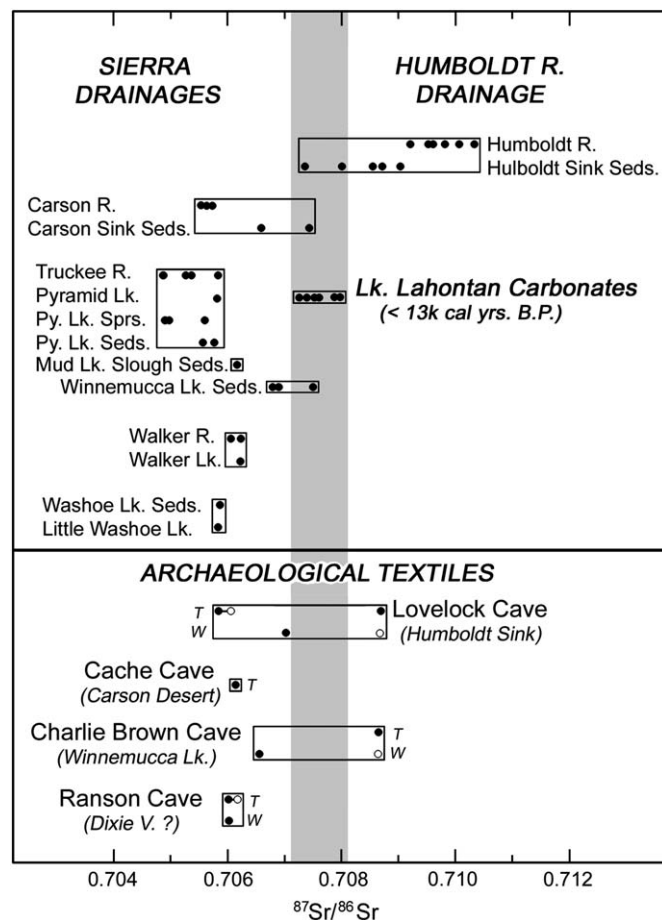


Fig. 4. <sup>87</sup>Sr/<sup>86</sup>Sr ratios for Lahontan Basin waters, synthetic soil waters, and archaeological textiles. Ratios for Lake Lahontan carbonates depicted by shaded bar. “W” refers to willow Lovelock Wickerware and “T” refers to open-weave tulle textiles. Textiles cleaned in a standard manner denoted by closed circles and deep-cleaned textiles denoted by open circles. Single specimens that received both standard and deep cleaning are joined by a bar. Data used in the figure were taken from Tables 1 and 2.

dissolved-metal compositions to distinguish between them. To forge a link between the chemical composition of a textile and the soil or stream water in which the plant grew, it may be possible to invoke the use of a trace-element distribution coefficient ( $K_D$ ) defined by

$$K_D(C_{TE1}/C_{TE2})_{\text{Soil water}} = (C_{TE1}/C_{TE2})_{\text{Plant}} \quad (2)$$

where  $C_{TE1}/C_{TE2}$  = the concentration ( $\mu\text{g element/g soil water or g plant}$ ) ratio of trace metals (TE) 1 and 2 [9].

The use of the distribution coefficient accounts for the bio-availability of chemical species (they are part of the soil-water solution), and the use of an elemental ratio negates the effect of changes in soil-water concentration on the concentrations of individual dissolved trace elements. However,  $K_D$  is not constant for all element ratios. Element pairs that contain a trace nutrient or a trace element that the plant prefers to exclude (e.g., lead) will exhibit widely varying  $K_D$  values. The  $K_D$  value will tend to be constant for element pairs that have similar chemical properties (e.g., the strontium–barium pair) if

those properties are neither essential nor harmful to the plant. The use of an elemental ratio also allows us to work with synthetic soil solutions produced by leaching a soil with a weak acid (see Section 2).

## 2. Methods

In order to define the  $^{87}\text{Sr}/^{86}\text{Sr}$  ratios of potential archaeological source areas we obtained water samples from the Carson, Truckee, and Humboldt rivers, and Little Washoe and Pyramid lakes (Fig. 2). Because of water diversion, perennial bodies of water no longer exist in the Winnemucca Lake Basin and in the Carson and Humboldt sinks. In those areas and in the Pyramid Lake Basin we obtained sediment samples which were leached with 1-M acetic acid for 48 h to produce a synthetic soil water (see methods section in [9]). Sr chemical separations and isotopic determinations on the natural and synthetic waters were conducted in a Class 1–10,000 clean room at the University of Colorado, Boulder, and Sr isotopic measurements were obtained using a Finnigan-MAT 261 thermal-ionization mass spectrometer in four-collector static mode (see methods section in [9]). The resulting  $^{87}\text{Sr}/^{86}\text{Sr}$  ratios as well as other pertinent Sr-isotope data reported in Ref. [5] have been listed in Tables 1 and 2.

Two clumps of tule and one clump of willow were sampled at the Mill City Bridge site on the Humboldt River to test whether the  $^{87}\text{Sr}/^{86}\text{Sr}$  ratios of these plant cuttings reflected the  $^{87}\text{Sr}/^{86}\text{Sr}$  ratios of the sediment pore fluids and stream water in which they were growing. The water and plant samples from the Mill City Bridge site have nearly identical  $^{87}\text{Sr}/^{86}\text{Sr}$  ratios (Table 3), indicating that the Sr-isotope chemistry of both willow and tule accurately reflect the Sr-isotope ratios of their source water(s).

Five tule and five Wickerware samples from Lovelock Cave, Cache Cave, Charlie Brown Cave and possibly Dixie Valley (Fig. 2B) were chosen for analysis. Samples of the archaeological textiles were dry ashed in platinum crucibles by ramping the temperature of the furnace in 50 °C increments every 30 min to a final temperature of 450 °C. The crucibles were allowed to cool to room temperature in the furnace before removal. After cooling, 2 ml of deionized water, 3 ml of high-purity concentrated  $\text{HNO}_3$ , and 2 ml of concentrated HF were added to the crucible. This solution was evaporated to dryness under an infrared heating lamp. After dissolving the residue in 22 ml of 10% (vol)  $\text{HNO}_3$ , the solution was diluted to 100 ml using 1% (vol)  $\text{HNO}_3$  (see methods section in [9]).

Modern willow and tule samples collected from several sites along the Carson, Humboldt, and Truckee rivers were wet-ashed by an acid-digestion procedure. This procedure consisted of weighing 0.1 g of freeze-dried sample into a closed polytetrafluoroethane container with 5 ml of high-purity concentrated  $\text{HNO}_3$ . This vessel was placed in a Milestone Model 1200 microwave digestion oven for about 30 min. After digestion, the cooled solution was diluted to volume in a 250-ml volumetric flask with deionized water.

To determine the degree to which burial had contaminated the textiles, additional portions of two prehistoric tule samples (26Ch5 1-21566 and Ranson DV#1) were aggressively cleaned

using a nylon scrubbing pad. Additional portions of two Wickerware samples (26Wa6914-92 and 26Ch5 1-19921) that had not been previously analyzed were “deep cleaned” by abrading with a nylon scrubbing pad followed by scrubbing with a diamond-impregnated sharpening block to remove all surface discoloration and contamination. These samples were then wet-ashed by an acid-digestion procedure.

This procedure consisted of weighing 0.2 g of homogenized sample into a closed polytetrafluoroethane container with 10 ml of high-purity concentrated  $\text{HNO}_3$ . These vessels were placed in an Applied Technical Services (ATS) Model 1100 microwave digestion oven for about 30 min. The volumes of the vessels used with the ATS microwave are about twice that previously used with the Milestone. Therefore, the total quantity of sample and volume of acid was adjusted to maintain similar digestion characteristics. After digestion, the cooled solution was diluted to volume in a 100-ml volumetric flask with deionized water. Prior to analysis, a further 1:10 dilution was made.

All samples collected for Sr-isotope analysis and willow and tule samples collected from several sites along the Carson, Humboldt, and Truckee rivers were subjected to trace-metal determinations using inductively coupled plasma-mass spectrometric (ICP-MS) and inductively coupled plasma-atomic emission spectrometric (ICP-AES) methods [13,26]. The trace-metal concentration data (Supplementary Table 1) were used to check for potential artifactual contamination of the archaeological textiles from soil silicates (e.g., the presence of excess Al in the textiles relative to Al values of modern tule and willow).

All plant samples were dried at 60 °C before performing oxygen-isotope ( $\delta^{18}\text{O}$ ) analysis of the bulk organic material.  $\delta^{18}\text{O}$  analyses were performed using a Eurovector elemental analyzer interfaced to a Micromass Isoprime stable-isotope-ratio mass spectrometer, after the method of Kornexl et al. [20]. Nickelized graphite is added to each sample to promote CO formation.  $\delta^{18}\text{O}$  results are reported in units of per mil Vienna Standard Mean Ocean Water (‰ VSMOW), and have an uncertainty of  $\pm 0.4\%$ .

## 3. Results

### 3.1. Oxygen isotopes

The  $\delta^{18}\text{O}$  values of present-day rivers emptying into the former Lahontan Basin have been altered by water diversion, reservoir construction, and irrigation practices. Evaporation of reservoir and irrigation water increases their  $\delta^{18}\text{O}$  values because the light isotope of oxygen ( $^{16}\text{O}$ ) is preferentially fractionated into the vapor phase [6]. Thus, reservoir effluent and irrigation return have enriched  $\delta^{18}\text{O}$  values. For example, precipitation in the Truckee River watershed has a weighted mean  $\delta^{18}\text{O}$  value of  $-14.2\%$ , yet the mean  $\delta^{18}\text{O}$  value of water from the Little Truckee River system which contributes  $\sim 2/3$  of the water in the mainstream Truckee River and which hosts three short-residence-time reservoirs is  $-12.4\%$  and the mean  $\delta^{18}\text{O}$  value of water from Lake Tahoe which has a long-residence

Table 1  
 $^{87}\text{Sr}/^{86}\text{Sr}$  ratios of Lahontan Basin surface waters, synthetic soil waters, upper Humboldt River source waters [5] and Sierran source rocks [19]

Sample	Site name	Location	Sample depth (cm)	$^{87}\text{Sr}/^{86}\text{Sr}$	$^{87}\text{Sr}/^{86}\text{Sr}$ error
<i>Truckee River Pyramid Lake waters</i>					
TR03-2	Truckee R above Little Truckee	10S 0750279 4363208		0.705819	0.000015
LTR03-1	Little Truckee R below Boca Dam	10S 0750273 4363538		0.704857	0.000012
JLTRF93-1	Truckee River at Farad 1993			0.705326	0.000008
TR93-1	Truckee River at Reno			0.705270	0.000050
TR04-1	Truckee river at Lockwood Bridge	11S 0272317 4376514		0.705256	0.000015
TR04-3	Truckee River at S-S Ranch	11S 0303841 4396210		0.705355	0.000013
PL93-1	Pyramid Lake			0.705800	0.000050
JLPL91-1	Pyramid Lake			0.705815	0.000010
JLPLNS91-1	Needles Spring			0.704960	0.000008
NS93-1	Needles Spring			0.704920	0.000050
NW93-1	Needles geothermal well			0.704890	0.000050
PLPRS93-1	Popcorn Rocks Spring			0.705590	0.000050
<i>Truckee River Pyramid Lake sediments</i>					
PLP#2	Pyramid Lake playa (Duck Lake)	11S 0292561 4412319	0–2	0.705751	0.000013
PLD#1	Pyramid Lake delta	11S 0291253 4413043	0–2	0.705557	0.000019
WDL#3	Mud Lake Slough	11S 0298664 4419115	50–60	0.706155	0.000016
WDL#1	Winnemucca Dry Lake south end	11S 0301781 4424238	50–58	0.706879	0.000012
WDL#2	Winnemucca Dry Lake south end	11S 0299775 4421937	35–46	0.706780	0.000015
WDL#4	Winnemucca Dry Lake north end	11T 0299702 4461733	33–36	0.707493	0.000016
<i>Washoe Lake water</i>					
LWL03-1	Little Washoe Lake	11S 0259345 4356530		0.705845	0.000015
<i>Washoe Lake sediment</i>					
WAL#1	Washoe Lake west shore	11S 0257947 4347565	0–2	0.705817	0.000009
<i>Carson River waters</i>					
JLCR93-1	East Fork Carson River 1993			0.705522	0.000008
CR93-1	Carson R. at Carson City			0.705610	0.000050
CR04-1	Carson River diversion at Mexican Ditch	11S 0265384 4337549		0.705714	0.000012
CR04-2	Carson River at Carson R. Rd at Piñon	11S 0266265 4335817		0.705692	0.000017
<i>Carson Sink sediments</i>					
CSSL#1	Carson Sink Goose Lake	11S 0374371 4384118	80–85	0.706573	0.000015
CSHC#1	Carson Sink Hidden Cave	11S 0359846 4363510	45–50	0.707414	0.000019
<i>Walker River Walker Lake waters</i>					
JLWWR93-1	West Walker River			0.706022	0.000011
WR93-1	Walker River at Wabuska			0.706200	0.000050
WL93-1	Walker Lake			0.706190	0.000050
<i>Humboldt River waters</i>					
JLHRE93-1	Humboldt R. at Elko 1993			0.709805	0.000010
HR93-1	Humboldt River at Elko			0.709510	0.000050
JLHRW93-1	Humboldt R. at Winnemucca 1993			0.709603	0.000010
HR04-4	Humboldt River at Mill City Bridge	11T 0408138 4505442		0.710321	0.000011
RPHR03-1	Humboldt R below Rye Patch Dam	11T 0389227 4480279		0.710055	0.000020
HR04-1	Humboldt River at Bridge near Lovelock Cave	11T 0374894 4434356		0.709191	0.000007
<i>Humboldt Sink sediments</i>					
HS#1	Humboldt Sink near Lovelock cave	11S 0365137 4425830	15–20	0.708697	0.000016
HS#2	Humboldt Sink near Lovelock cave	11S 0364765 4425907	15–20	0.709018	0.000016
HS#3	Humboldt Sink bank of Humboldt R.	11T 0374952 4434393	150–155	0.708537	0.000016
HS04-1	Playa NW of Lovelock cave	11T 0372256 4430234	10–15	0.707340	0.000013
HS04-2	Playa NW of Lovelock cave	11T 0370587 4429097	10–15	0.707996	0.000012
<i>Upper Humboldt Source Waters</i>					
0709-6-90	Near Williams Spring	115°44'20" 40°02'45"		0.70974	0.00003
0710-1-90	Near Harrison Creek Pass	115°29'25" 40°18'55"		0.71009	0.00002
0710-2-90	Longhair Smith Canyon Creek	115°29'31" 40°19'49"		0.71026	0.00003

(continued on next page)

Table 1 (continued)

Sample	Site name	Location	Sample depth (cm)	$^{87}\text{Sr}/^{86}\text{Sr}$	$^{87}\text{Sr}/^{86}\text{Sr}$ error
0710-3-90	S. Fork of Greem Mountain Creek	115°29'41" 40°21'11"		0.71048	0.00002
0710-6-90	Unnamed Springs	115°30'43" 40°18'06"		0.70943	0.00002
0711-1-90	Unnamed Springs	115°32'14" 40°19'57"		0.70982	0.00003
0711-3-90	Unnamed Spring on Creek Above Lamoille Lk	115°21'51" 40°37'38"		0.71131	0.00003
0711-5-90	Unnamed Springs in Scenic Area	115°22'58" 40°38'53"		0.71146	0.00003
0711-6-90	Gaging Station	115°28'20" 40°41'34"		0.71198	0.00003
JD-900710-1	East Harrison Pass Seep	115°29'30" 40°18'56"		0.71015	0.00002
JD-900710-4	Banana Pond	115°31'49" 40°06'46"		0.70922	0.00003
JD-900710-5	County Line Pond	115°31'39" 40°07'27"		0.70929	0.00002
JD-900710-6	East County Line Pond	115°31'34" 40°07'26"		0.70921	0.00003
JD-900710-8	Snake Spring	115°29'07" 40°13'21"		0.71054	0.00001
JD-900710-9	First Spring	115°27'59" 40°15'07"		0.71021	0.00003
JD-900711-1	West Harrison Pass Seep	115°35'09" 40°20'07"		0.70930	0.00003
JD-900711-2	Northwest Harrison Pass Channel	115°32'17" 40°19'57"		0.70987	0.00002
JD-900711-3	Ruby Mountain Divide Spring	115°29'41" 40°21'16"		0.71057	0.00003
JD-900712-1	Upper Cherry Spring	115°37'10" 40°03'47"		0.71175	0.00005
JD-900712-2	Lower Cherry Spring	115°37'27" 40°03'29"		0.71149	0.00002
0709-4-90	Gallager Fish Hatchery	115°29'20" 40°11'01"		0.71044	0.00014
JD-900710-2	Gallager Fish Hatchery	115°29'28" 40°11'05"		0.70998	0.00003
JD-900710-3	E. Gallager Fish Hatchery	115°29'27" 40°11'03"		0.70986	0.00005
JD-900710-7	Ruby Marshes	115°30'26" 40°08'09"		0.70934	0.00003
0709-2-90	N. Sump of Ruby Lake	115°27'04" 40°00'01"		0.71020	0.00002
0709-3-90	N. Sump of Ruby Lake	115°29'01" 40°13'00"		0.71053	0.00003
0709-5-90	S. Sump of Ruby Lake	115°30'27" 40°08'19"		0.70932	0.00003
JD-900711-7	E. Sump of Ruby Lake	115°25'36" 40°14'00"		0.70842	0.00003
JD-900711-4	Hot Spring #1	115°24'22" 40°15'07"		0.70900	0.00002
JD-900711-5	Hot Spring #2	115°24'27" 40°15'08"		0.70901	0.00003
JD-900711-6	Scirpus Swamp Hot Springs	115°24'29" 40°15'09"		0.70907	0.00002
JD-900709-1	Williams Spring	115°44'21" 40°02'45"		0.70987	0.00003
JD-900712-3	Pete Holm Spring	115°41'36" 40°04'21"		0.71024	0.00002
JD-900713-1	Chimney Spring	116°09'53" 40°00'19"		0.70891	0.00003
JD-900713-2	Flynn Spring	116°05'24" 40°09'18"		0.71320	0.00003
JD-900713-3	Matthews Stock Spring	116°04'51" 40°12'20"		0.71002	0.00003
JD-900713-4	Mill Creek Valley Seep	116°03'41" 40°30'07"		0.71322	0.00003
<i>Sierran Source Rocks</i>					
4	Mesozoic Granite			0.7057	0.0001
5	Mesozoic Granite			0.7058	0.0001
6	Mesozoic Granite			0.7035	0.0001
7	Mesozoic Granite			0.7062	0.0001
8	Mesozoic Granite			0.7066	0.0001
9	Mesozoic Granite			0.7074	0.0001
11	Mesozoic Granite			0.7069	0.0001

Samples beginning with JL are from an unpublished 1996 Columbia University PhD thesis by J. Lin entitled "U-Th,  $^{14}\text{C}$ , and Sr Isotopic Studies of Late Pleistocene Hydrological Events in Western Great Basin, Nevada and California".

time and contributes  $\sim 1/3$  of the water in the mainstream Truckee (via its outlet at Tahoe City) is  $-5.5\text{‰}$  (Table 4) [3]. Thus, the presence of Lake Tahoe and other reservoirs in the headwaters of the Truckee River increases the mean  $\delta^{18}\text{O}$  value of river water to  $-10.3\text{‰}$  at Farad, California (Table 4).

The effect of irrigation on the downstream  $\delta^{18}\text{O}$  values of river water is illustrated by the Humboldt River system (Fig. 2, Table 4). The mean  $\delta^{18}\text{O}$  value of headwaters input to the Humboldt River is about  $-14\text{‰}$ , judging from surface-water values at Imlay, Nevada, and precipitation values from Ruby Valley (Table 4). The river sites in Table 4, which are arranged in a downstream manner, indicate that the  $\delta^{18}\text{O}$  values of the heavily diverted Humboldt River increase by  $3.8\text{‰}$  from Mill City Bridge B572 to Bridge B1618. The  $\delta^{18}\text{O}$  values of tule and willow growing along the Humboldt reflect the downstream increasing surface-water  $\delta^{18}\text{O}$  values

with tule values increasing by  $3.3\text{‰}$  and willow values increasing by  $4.8\text{‰}$  (Table 5).

Prior to the introduction of agriculture to the Lahontan Basin, ca. AD 1850, the  $\delta^{18}\text{O}$  values of the Humboldt and Carson rivers would have been similar to their headwater values (about  $-14\text{‰}$ ). Between ca. 1550 BC and AD 1850, the Truckee River  $\delta^{18}\text{O}$  value would have been about  $3\text{‰}$  heavier ( $-11\text{‰}$ ) due to input from Lake Tahoe; however, during the dry middle Holocene (8000–3500 cal B.P./1550 BC), Lake Tahoe did not spill [8] and the Truckee River  $\delta^{18}\text{O}$  value would also have been about  $-14\text{‰}$ .

### 3.2. Sr isotopes

$^{87}\text{Sr}/^{86}\text{Sr}$  ratios of Humboldt River water reflect the  $^{87}\text{Sr}/^{86}\text{Sr}$  ratios of its headwater sources (Ruby Mountains



Table 2  
 $^{87}\text{Sr}/^{86}\text{Sr}$  ratios of archaeological textiles

Sample	Site name, archaeological textiles	$^{87}\text{Sr}/^{86}\text{Sr}$	$^{87}\text{Sr}/^{86}\text{Sr}$ error
26Ch5 1-201??	Lovelock Cave, open-twined tule weft	0.708695	0.000016
26Ch5 1-21566	Lovelock Cave, open-twined tule matting	0.705837	0.000009
26Ch5 1-21566 clean	Lovelock Cave, open-twined tule matting	0.706057	0.000012
26Ch5 1-19920	Lovelock Cave, Lovelock Wickerware	0.707122	0.000029
26Ch5 1-19921 clean	Lovelock Cave, Lovelock Wickerware	0.708677	0.000011
26Ch1H 1-1H-6	Cache Cave, open-twined tule matting	0.706126	0.000025
26Wa6914 18a	Charlie Brown Cave, open-twined tule matting	0.708622	0.000022
26Wa6914 12t	Charlie Brown Cave, Lovelock Wickerware	0.706533	0.000019
26Wa6914-92 clean	Charlie Brown Cave, Lovelock Wickerware	0.708618	0.000016
Ranson DV#1	Dixie Valley?, open-twined tule matting	0.706175	0.000014
Ranson DV#1 clean	Dixie Valley?, open-twined tule matting	0.706329	0.000017
Ranson DV#2	Dixie Valley?, Lovelock Wickerware	0.706192	0.000014

“Clean” refers to deep-cleaned textiles.

and the nearby Sulfur Spring Range, and Piñon Ranges of northeastern Nevada) (Fig. 2A), and the  $^{87}\text{Sr}/^{86}\text{Sr}$  ratios of the Truckee and other rivers that drain the Sierra Nevada reflect the bedrock  $^{87}\text{Sr}/^{86}\text{Sr}$  ratios of their source regions [5,19] (Figs. 2, 4, and 5A, Table 1). However, the  $^{87}\text{Sr}/^{86}\text{Sr}$  ratios of synthetic soil waters derived from Winnemucca Lake basin, Carson Sink, and Humboldt Sink sediments are shifted from their source water values, causing the  $^{87}\text{Sr}/^{86}\text{Sr}$  ratios of these ephemeral playa sediment waters to overlap (Fig. 4).

We believe that the shift in the  $^{87}\text{Sr}/^{86}\text{Sr}$  ratios is due to mixing of river-derived Sr with Sr from carbonates deposited in Lake Lahontan sediments. The  $^{87}\text{Sr}/^{86}\text{Sr}$  ratio of water in each of the Lahontan subbasins changed over time during the late Wisconsin when Humboldt River water mixed with Sierran river water [5]. During that time, when the level of Lake Lahontan exceeded the elevation of Emerson Pass Sill (1207 m) (Fig. 5B), waters in the Pyramid Lake and Winnemucca Lake subbasins, derived from the Truckee River, mixed with waters from the Black Rock Desert—Smoke Creek Desert and Carson Desert subbasins, derived from the Carson and

Humboldt rivers. The  $^{87}\text{Sr}/^{86}\text{Sr}$  ratio in Lake Lahontan carbonates ranged from 0.707 to 0.708 between 25,000 and 13,000 cal B.P. when lake levels exceeded 1207 m (Fig. 5A, Supplementary Table 1).

During the Holocene, waters in the Humboldt and Carson Sink areas of the Carson Desert subbasin also mixed when sink-water elevations exceeded 1189 m, a phenomenon which has been argued to have occurred between AD 430 and 640, between AD 1035 and 1300 [1], and during the historical period [22]. Therefore, the  $^{87}\text{Sr}/^{86}\text{Sr}$  ratio of willow or tule that grew along the edge of Winnemucca Lake or along the edges of the Carson and Humboldt sinks would have been a function of the relative amount of Sr derived from surface-water input plus the amount of Sr derived from dissolution of root-zone soil carbonate. On the other hand, if the plants grew on sandbars or along banks of perennial surface-water systems, their  $^{87}\text{Sr}/^{86}\text{Sr}$  ratios would be nearly identical to isotope ratios of Sr dissolved in river water.

### 3.3. Trace metals

A comparison of trace-metal concentrations in the three rivers indicates relatively high concentrations of As, B, K, Mg, Mo, Na, Rb, Sb, Sr, Te, U, and V in the Humboldt River; however, only Humboldt River tule indicates elevated concentrations of one of those metals – Rb – relative to tule from the other rivers (Supplementary Table 1). For some elements (As, B, Sb and Te) this may, in part, be due to the loss of these elements by volatilization during the dry ashing process.

The data in Supplementary Table 1 were used to check for distribution coefficients that yielded “minimal” variability. Three elemental pairs (Ba/Sr, Mg/Sr, and Ca/Sr) yielded the most stable results (Table 6). However, variability in the values of the distribution coefficients (standard deviations ranged from 33 to 52%), combined with overlap in the elemental ratios from the three rivers (Supplementary Table 1), renders negligible the application of distribution coefficients to textile sourcing in the Lahontan Basin.

A comparison of modern plant-elemental chemistry with archaeological-textile chemistry indicates that a number of elements that are below detection in the modern tule and willow are detectable in the textiles; e.g., the rare-earth elements (REE) (Y, La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu) (Supplementary Table 1). In addition, the concentration of Al, a common element contained in rock-forming aluminosilicate minerals, is strongly elevated in the textiles. This suggests that some of the archaeological textiles have been

Table 3  
 $^{87}\text{Sr}/^{86}\text{Sr}$  ratios of plant and water samples from the Mill City Bridge 572 site on the Humboldt River, Nevada

Sample	Site name	Location (UTM NADS 27)	$^{87}\text{Sr}/^{86}\text{Sr}$	$^{87}\text{Sr}/^{86}\text{Sr}$ error
HR04-4 stream H <sub>2</sub> O	Humboldt River at Mill City Bridge 572	11T 0408138 4505442	0.710321	0.000011
HR04-4 sediment H <sub>2</sub> O	Pore Fluid at Mill City Bridge 572	11T 0397107 4505090	0.710277	0.000015
HR04-4 wil2	Mill City Bridge 572	11T 0397107 4505090	0.710215	0.000018
HR04-4 tul1	Mill City Bridge 572	11T 0397107 4505090	0.710241	0.000011
HR04-4 tul2	Mill City Bridge 572	11T 0397107 4505090	0.710242	0.000015

The sediment–water sample was taken from the base of the tules. Plant samples include tule (tul) and willow (wil).

Table 4  
 $\delta^{18}\text{O}$  values of Tahoe Meadows and Ruby Valley precipitation and water samples taken from the Carson, Humboldt, and Truckee rivers

Sample	Site name	Collection date	Samples	$\delta^{18}\text{O}$ (‰)	Location (UTM NADS 27)
<i>Carson River Surface-Water System</i>					
	Carson R., E. Fork at Gardnerville	5/30/1985 to 8/26/1986	16	−13.9	
	Carson R., W. Fork at Woodfords	5/30/1985 to 9/1/1987	27	−14.3	
CR04-1	Carson R., Mexican Ditch Wetland	6/7/2004	1	−12.9	11S 265384 4337549
CR04-2	Carson R. Road at Pinon	6/7/2004	1	−13.9	11S 266265 4335817
CR04-3	Carson R. Downstream from Buckland Sta.	6/7/2004	1	−13.8	11S 307046 4350845
CR04-5	Carson R.	6/7/2004	1	−13.7	11S 309976 4351333
CR04-4	Carson R. Floodplain, Hercules Pond	6/7/2004	1	−12.2	11S 312278 4353108
<i>Humboldt River Surface-Water System</i>					
	Ruby Valley Precipitation	1/16/1986 to 7/21/1987	62	−13.2	
	Humboldt R. at Imlay	7/25/1985 to 8/26/1986	15	−13.6	
HR04-4	Humboldt R. at Mill City Bridge 572	6/8/2004	1	−12.5	11T 408138 4505442
HR04-5	Humboldt R. at Calahan Bridge B1620	6/8/2004	1	−11.7	11T 397107 4505090
HR04-3	Humboldt R. at Old Pit Dam	6/8/2004	1	−10.2	11T 379141 4454584
HR04-2	Humboldt R. at Spillway	6/8/2004	1	−7.4	11T 374911 4434753
HR04-1	Humboldt R. at Bridge B1618	6/8/2004	1	−8.7	11T 374894 4434356
<i>Truckee River Surface-Water System</i>					
	Tahoe Meadows Precipitation	10/21/1985 to 1/2/1990	134	−14.2	
	Truckee R. at Tahoe City	6/3/85 to 11/2/87	30	−5.5	
	Little Truckee R. above Boca Reservoir	6/6/1985 to 10/11/1986	16	−12.4	
	Truckee R. at Farad	6/5/1985 to 9/1/1993	54	−10.3	
TR04-4	Truckee R., Oxbow Wetland in Reno	6/9/2004	1	−10.4	11S 255230 4377916
TR04-1	Truckee R. at Lockwood Bridge	6/9/2004	1	−11.1	11S 272317 4376514
TR04-2	Truckee R. at Wadsworth Bridge	6/9/2004	1	−11.4	11S 304212 4389209
TR04-3	Truckee R. at S-S Ranch	6/9/2004	1	−11.3	11S 303841 4396210
	Truckee R. at Nixon	6/5/1985 to 9/1/1993	43	−10.6	
	Pyramid Lake	1/7/1991 to 1/4/1994	71	−1.0	

Data for unnumbered samples are from Refs. [3,6] and unpublished data of L. Benson.

contaminated with soil. However, this does not necessarily imply that the textiles were contaminated with Sr because most aluminosilicates contain little or no Sr.

To test for Sr and other metal contamination, four samples were carefully cleaned and analyzed (see Section 2). Two of the carefully cleaned tule samples had also been analyzed prior to cleaning. The trace-metal data clearly indicate that substantial amounts of Al and REE were removed by cleaning (Supplementary Table 1). However, the  $^{87}\text{Sr}/^{86}\text{Sr}$  ratios of the clean samples were only shifted about two parts in the fourth decimal place (Table 2), indicating that while it is important to “deep clean” archaeological textiles, the degree of contamination did not affect the conclusions of this paper.

## 4. Discussion

### 4.1. $\delta^{18}\text{O}$ as an indicator of water-body type

In the past, the  $\delta^{18}\text{O}$  values of shallow waters in the Carson Sink, Humboldt Sink, and Winnemucca Lake subbasin would have been substantially more enriched than the rivers that flowed into them; e.g., the present-day hydrologically closed Pyramid Lake has a mean  $\delta^{18}\text{O}$  value of  $-1\text{‰}$  (Table 4). This implies that plants which were the sources of prehistoric archaeological textiles that grew along the margins of sinks or lakes also would exhibit highly enriched  $\delta^{18}\text{O}$  values. If, for example, we assume that the sinks and lakes had  $\delta^{18}\text{O}$  values ranging from  $-1$  to  $-3\text{‰}$ , and that the fractionation factor from

water to plant is  $\sim 34\text{‰}$  (Table 7), a plant that grew in such an environment would have a  $\delta^{18}\text{O}$  value between 31 and 33‰. In fact, none of the textiles possess such enriched  $\delta^{18}\text{O}$  values, instead most of their values fall within the range (20–24‰) expected if they were harvested from riverine environments (Table 8). The riverine environments would include marsh and deltaic habitats [16,18], both of which could support stands of willow [24, plate 4a]. This implies that the strontium- and oxygen-isotope values of the textiles also were derived from riverine sources and not from stagnant multiple-source water that filled a sink area. Modern analogs of such environments might include the Carson River floodplain near Hercules Pond or the Oxbow Wetland along the Truckee River (Table 4).

### 4.2. $^{87}\text{Sr}/^{86}\text{Sr}$ ratio as an indicator of textile source

A willow Wickerware sample from Lovelock Cave (26Ch5 1-19920) has a  $^{87}\text{Sr}/^{86}\text{Sr}$  ratio that falls between values for Sierran rivers and the Humboldt River and may represent a mixture of sources; i.e., either the willow grew in a mixture of waters having different  $^{87}\text{Sr}/^{86}\text{Sr}$  ratios (inherited from the river water and the soluble minerals in the soil) or the Wickerware was composed of a mixture of willows taken from two rivers having different  $^{87}\text{Sr}/^{86}\text{Sr}$  ratios. Given that the textiles analyzed in this study came from riverine sources, we favor the latter explanation. A deep-cleaned sample of Wickerware from the same site (26Ch5 1-19920) has a  $^{87}\text{Sr}/^{86}\text{Sr}$  ratio consistent with a Humboldt River origin.

Table 5  
 $\delta^{18}\text{O}$  values of tule (tul) and willow (wil) samples from the Carson, Humboldt, and Truckee river systems

Carson River	$\delta^{18}\text{O}$ (‰)	Location (UTM NADS 27)	Humboldt River	$\delta^{18}\text{O}$ (‰)	Location (UTM NADS 27)	Truckee River	$\delta^{18}\text{O}$ (‰)	Location (UTM NADS 27)
CR04-1 tul1-A	22.8	11S 0265384 4337549	HR04-4 tul1-A	21.7	11T 0408138 4505442	TR04-4 tul1-A	23.4	11S 0255230 4377916
CR04-1 tul1-B	23.0	11S 0265384 4337549	HR04-4 tul1-B	22.0	11T 0408138 4505442	TR04-4 tul2-A	22.5	11S 0255230 4377916
CR04-1 tul1-C	22.7	11S 0265384 4337549	HR04-4 tul2-A	22.7	11T 0408138 4505442	TR04-1 tul1-A	21.6	11S 0272317 4376514
CR04-1 tul2-A	22.3	11S 0265384 4337549	HR04-5 tul1-A	22.7	11T 0397107 4505090	TR04-1 tul2-A	21.4	11S 0272317 4376514
CR04-1 tul2-B	22.0	11S 0265384 4337549	HR04-5 tul1-B	23.3	11T 0397107 4505090	TR04-2 tul1-A	23.2	11S 0304212 4389209
CR04-1 tul2-C	22.5	11S 0265384 4337549	HR04-3 tul1-A	24.8	11T 0379141 4454584	TR04-2 tul1-B	21.9	11S 0304212 4389209
CR04-4 tul1-A	21.0	11S 0312278 4353108	HR04-3 tul2-A	24.4	11T 0379141 4454584	TR04-3 tul1-A	24.4	11S 0303841 4396210
CR04-4 tul2-A	24.3	11S 0312278 4353108	HR04-1 tul1-A	25.1	11T 0374894 4434356	TR04-3 tul2-A	22.8	11S 0303841 4396210
CR04-4 tul2-B	24.4	11S 0312278 4353108	HR04-1 tul2-A	25.4	11T 0374894 4434356	TR04-3 tul2-B	23.7	11S 0303841 4396210
			HR04-1 tul2-B	25.0	11T 0374894 4434356			
ave. plant	22.8			23.7			22.8	
s.d. plant	1.1			1.4			1.0	
ave. clump	22.6			23.9			22.7	
CR04-2 wil1-A	23.4	11S 0266265 4335817	HR04-4 wil1-A	21.8	11T 0408138 4505442	TR04-4 wil1-A	21.8	11S 0255230 4377916
CR04-2 wil1-B	24.0	11S 0266265 4335817	HR04-4 wil1-B	22.3	11T 0408138 4505442	TR04-4 wil2-A	23.3	11S 0255230 4377916
CR04-2 wil1-C	23.5	11S 0266265 4335817	HR04-4 wil2-A	20.8	11T 0408138 4505442	TR04-1 wil1-A	21.4	11S 0272317 4376514
CR04-2 wil2-A	22.8	11S 0266265 4335817	HR04-5 wil1-A	20.5	11T 0397107 4505090	TR04-1 wil2-A	22.3	11S 0272317 4376514
CR04-2 wil2-B	20.3	11S 0266265 4335817	HR04-5 wil2-A	20.8	11T 0397107 4505090	TR04-1 wil2-B	23.0	11S 0272317 4376514
CR04-2 wil2-C	23.9	11S 0266265 4335817	HR04-3 wil1-A	24.2	11T 0379141 4454584	TR04-2 wil1-A	22.2	11S 0304212 4389209
CR04-3 wil1-A	21.9	11S 0307046 4350845	HR04-3 wil2-A	24.6	11T 0379141 4454584	TR04-3 wil1-A	22.5	11S 0303841 4396210
CR04-3 wil2-A	21.3	11S 0307046 4350845	HR04-2 wil1-A	24.6	11T 0374911 4434753	TR04-3 wil2-A	24.1	11S 0303841 4396210
CR04-3 wil2-B	21.1	11S 0307046 4350845	HR04-2 wil2-A	24.8	11T 0374911 4434753	TR04-3 wil2-B	24.1	11S 0303841 4396210
CR04-5 wil1-A	19.1	11S 0309976 4351333	HR04-2 wil2-B	25.3	11T 0374911 4434753			
ave. plant	22.1			23.6			22.7	
s.d. plant	1.7			2.0			1.0	
ave. clump	21.6			22.8			22.6	

“ave.” indicates average value and “s.d.” indicates standard deviation of individual plants and clumps of plants containing one or more individual samples.

The two tule mat fragments from Lovelock Cave clearly come from two different drainages with one specimen (26Ch5 1-21566) reflecting collection from a Sierran drainage and the other specimen (26Ch5 1-201??) indicating collection from the Humboldt River system.

The plants used to fabricate both questionable Dixie Valley specimens (Ranson DV#1, DV#2) are clearly from rivers that drain the Sierra. Given that the closest Sierran river is the Carson which discharges to the Carson Desert, we favor this stream as the source of the Dixie Valley specimens. The Carson Desert, Cache Cave tule mat fragment (26Ch1H 1-1H-6) and the Dixie Valley textiles have nearly identical  $^{87}\text{Sr}/^{86}\text{Sr}$  ratios also supporting a Carson River origin for the Dixie Valley materials.

The  $^{87}\text{Sr}/^{86}\text{Sr}$  ratio value of one willow Wickerware fragment (26Wa6914-12t) from Charlie Brown Cave on the east side of Winnemucca Lake Basin falls within the range of  $^{87}\text{Sr}/^{86}\text{Sr}$  ratios of sediments from Winnemucca (Dry) Lake and Mud Lake Slough on the southern end of the lake basin. It is tempting to suggest that the willow grew at the southern end of the lake basin; however, the  $\delta^{18}\text{O}$  value of the Wickerware (19.8‰) points to a riverine origin (e.g., the Truckee River) for the plant. Riverine origin could include an active slough or a marsh upstream of the river mouth that was the site of running water. The other Wickerware sample (26Wa6914-92) is consistent with a Humboldt River origin. The tule mat sample from Charlie Brown Cave (26Wa6914-18a) also appears to have derived its Sr from a Humboldt River

source and has a  $^{87}\text{Sr}/^{86}\text{Sr}$  ratio very similar to one of the Lovelock Cave tule mat samples (26Ch5 1-201??).

#### 4.3. Trace-metal ratios as an indicator of textile source

The use of plant trace-metal ratios to distinguish between rivers that head in the Sierra Nevada was not successful. This is because (1) the distribution coefficients used to describe the metal partitioning between water and plant were highly variable (Table 6), and (2) metal ratios in the rivers are very similar.

### 5. Conclusions and suggestions for future work

This study, while exploratory in nature, has demonstrated that strontium and oxygen isotopes of archaeological textiles from the western Great Basin can be used to distinguish the hydrological environment (stream/marsh or sink/playa/lake) and drainage system (Sierra Nevada vs. Humboldt River drainage) in which the archaeological plant (willow or tule) grew. However, the application of trace-element distribution coefficients to water–plant metal fractionation did not allow us to distinguish between the various rivers (Carson, Truckee, Walker) which head in the Sierra Nevada.

The  $\delta^{18}\text{O}$  values of the textiles indicate that the chemistry of the 10 samples reflect a riverine source that may include marsh environments. With respect to willow, a riverine source of textiles is not unexpected as many willows are only slightly

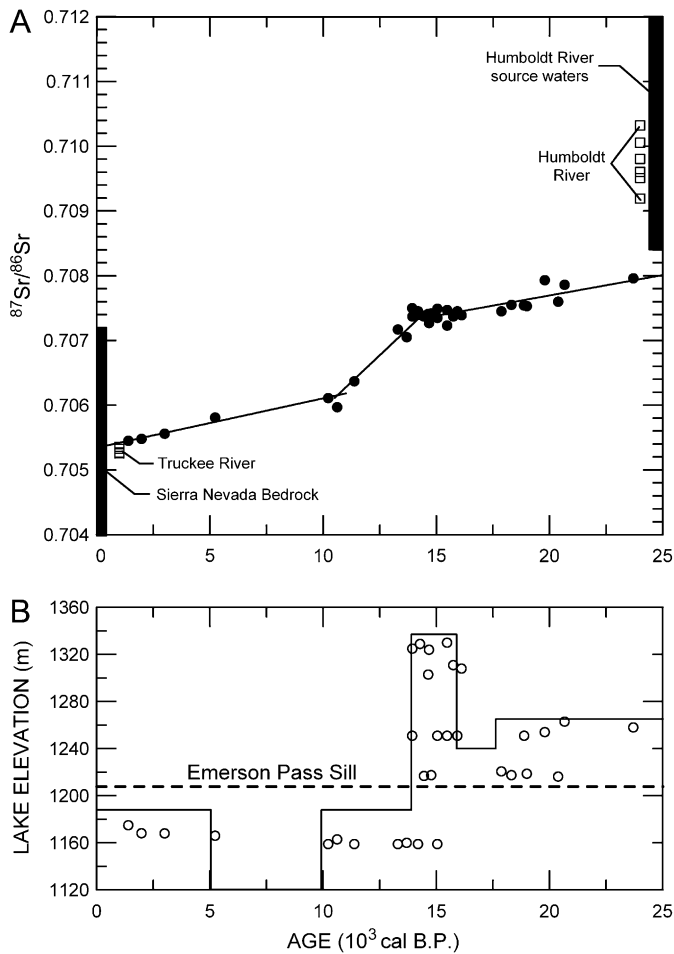


Fig. 5. (A)  $^{87}\text{Sr}/^{86}\text{Sr}$  evolution of Lake Lahontan. Range of  $^{87}\text{Sr}/^{86}\text{Sr}$  ratios of Humboldt and Sierran River source rocks/waters are shown as solid vertical bars. Present-day river water  $^{87}\text{Sr}/^{86}\text{Sr}$  ratios are shown as open squares and  $^{87}\text{Sr}/^{86}\text{Sr}$  ratios of carbonates precipitated from Lake Lahontan are shown as solid circles. Data from which this figure was constructed are listed in Supplementary Table 2. (B) Elevation history of Lake Lahontan. When water levels in Smoke Creek Desert–Black Rock Desert subbasin and Pyramid Lake subbasin exceed 1207 m (Emerson Pass Sill), the lakes in both subbasins coalesce forming a single water body.

saline tolerant; e.g., *S. exigua* (coyote or sandbar willow), one of the most salinity tolerant willows, will succumb when conductivity exceeds 4 dS/m. In addition, willows cannot survive the permanent flooding that may be associated with sink and shallow-lake environments.

Samples found in Dixie Valley (Ranson DV-1, DV-2), Cache Cave (26Ch1H 1-1H-6), and one tule sample from Lovelock Cave (26Ch5 1-21566) appear to have obtained their

Table 6

Averages (ave.) and standard deviations (s.d.) for willow and tule Ba/Sr, Mg/Sr, and Ca/Sr distribution coefficients ( $K_D$ )

Plant type	$K_D$		
	Ba/Sr	Mg/Sr	Ca/Sr
ave. willow	1.83	0.39	0.61
s.d. willow	0.64	0.13	0.23
ave. tule	8.62	0.85	0.87
s.d. tule	3.99	0.44	0.29

Table 7

Tule–H<sub>2</sub>O and willow–H<sub>2</sub>O  $\delta^{18}\text{O}$  fractionation factors (FF)

Sample	Tule-water FF (‰)	Site no.	Willow-water FF (‰)
CR04-1	35.5	CR04-2	36.8
CR04-4	35.4	CR04-3	35.2
HR04-4	34.6	CR04-5	32.8
HR04-5	34.7	HR04-4	34.1
HR04-3	34.8	HR04-5	34.4
HR04-1	33.9	HR04-3	34.6
TR04-4	33.4	HR04-2	32.3
TR04-1	33.6	TR04-4	33.0
TR04-2	34.0	TR04-1	33.3
TR04-3	34.9	TR04-2	33.6
		TR04-3	34.9
ave.	34.5		34.1
s.d.	0.7		1.3

Sr from Sierra Nevada streams. One willow Wickerware sample from Charlie Brown Cave (26Wa6914-12t) also appears to have obtained its Sr from a Sierran stream although its  $^{87}\text{Sr}/^{86}\text{Sr}$  ratio is somewhat elevated.

On the other hand, a tule and a willow sample from Lovelock Cave (26Ch5 1-201??, 26Ch5 1-19921) and a tule and willow sample from Charlie Brown Cave (26Wa6914-18a, 26Wa6914-92) would appear to have derived their Sr from the Humboldt River. A willow Wickerware sample from Lovelock Cave (26Ch5 1-19920) has a  $^{87}\text{Sr}/^{86}\text{Sr}$  ratio that falls between values for Sierran rivers and the Humboldt River and may represent a mixture of willow from two river sources. These data suggest that at times inhabitants of the various rock shelters may have gathered raw plant materials from local sources and at other times they either gathered plants from distant sources or exchanged materials or completed textiles with other groups located at distant sources.

Contamination of the archaeological textile with sediment from a rock shelter is an issue that must be explicitly dealt with in future studies. Tule is easily contaminated but extremely difficult to clean given the thinness of its walls. Selection of extremely well preserved, whole (un-split) tule specimens is very important. This is relatively easy to achieve for whole stem matting, but less so with split stem baskets and matting. Whole willow-warp rods are probably a more reliable indicator of the plant's Sr uptake than split-willow warp or weft elements. Because willow wefts are split, exposing the

Table 8

Textile  $\delta^{18}\text{O}$  values

Sample	Plant type	$\delta^{18}\text{O}$ (‰)
Ranson DV-1	Tule	17.4
Ranson DV-2	Willow	23.9
26Ch1H 1-1H-6	Tule	22.8
26Ch5 1-21566	Tule	25.4
26Ch5 1-19920	Willow	20.0
26Ch5 1-19921	Willow	18.2
26Ch5 1-201??	Tule	20.2
26Wa6914-92	Willow	21.4
26Wa6914-18a	Tule	22.7
26Wa6914-12t	Willow	19.8

pith, they may be more easily contaminated with cave sediments than whole willow rods. To remove contamination, a textile sample should first be “deep cleaned” by abrading with a nylon scrubbing pad followed by scrubbing with a diamond-impregnated sharpening block to remove all surface discoloration and contamination. The samples can then be wet-ashed by an acid-digestion procedure and checked for elevated concentrations of Al or Ca or other metals associated with aluminosilicates or carbonates found in cave-floor sediments. As samples of Carson Desert Lovelock Wickerware are small in size and rare, sample weights are limited. The metal data presented in this paper indicate that 0.5 g of clean, whole willow rod will provide an adequate sample for  $\delta^{18}\text{O}$ ,  $^{87}\text{Sr}/^{86}\text{Sr}$ , and trace-metal analyses.

Optimally, a large number of clean well-dated samples of Lovelock Wickerware and Lovelock coiled basketry should be analyzed from one or more rock shelters from the western Great Basin. Lovelock coiled basketry should be included in the study to determine if the functional and technological types associated with this Wickerware were differentially distributed. Analyzing a sequence of the Lovelock textiles should allow determination of changing material sources with time and should help to answer the question of the origin of Carson Desert Lovelock Wickerware.

## Acknowledgments

The authors benefited from discussions with Catherine Fowler, Don Grayson, Alvin McLane, Pat Barker, and Robert Elston. David Critchfield assisted in sample preparation. We also thank two anonymous reviewers, Deborah Martin, and Blaine McClesky for reviews of an earlier version of this manuscript. Any use of trade, product, or firm names in this paper does not imply endorsement by the U.S. government.

## Appendix A. Supplementary data

Supplementary tables associated with this article can be found, in the online version, at doi: [10.1016/j.jas.2006.02.012](https://doi.org/10.1016/j.jas.2006.02.012).

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Supplementary Table 2. Age, elevation and  $^{87}\text{Sr}/^{86}\text{Sr}$  ratio of carbonate deposits from the Lahontan Basin, Nevada [5]. Age is in thousands of calendar years and was calculated using [17] or [25] after correcting for a 600-year radiocarbon reservoir effect.

$^{14}\text{C}$ Lab Number	Sample	Locality	Elevation (m)	Age (cal ka)	$^{87}\text{Sr}/^{86}\text{Sr}$
<b>Young branching tufa</b>					
W-6429	PL91-601b	Marble Bluff	1251	13.93	0.70750
W-6391	PL91-503	Doghead Rock	1217	14.77	0.70742
CAMS-5774	PLBT93-1e1	Blanc Tetons	1159	14.19	0.70745
W-6393	PL91-504	Doghead Rock	1217	14.45	0.70737
CAMS-6235	PL90-108	Marble Bluff	1251	15.04	0.70749
CAMS-5775	PLBT93-1e2	Blanc Tetons	1159	15.04	0.70735
W-6428	PL91-601a	Marble Bluff	1251	15.48	0.70747
W-6431	PL91-603	Marble Bluff	1251	15.93	0.70745
W-6330	PL90-107	Doghead Rock	1221	17.87	0.70745
W-6323	PL90-106	Doghead Rock	1218	18.32	0.70755
W-6433	PL91-605	Marble Bluff	1251	18.87	0.70754
W-6394	PL91-505	Doghead Rock	1219	19.00	0.70753
W-6324	PL90-101	Doghead Rock	1216	20.38	0.70760
<b>Miscellaneous dense tufa coatings from between 1207 and 1308 m</b>					
CL-4240179	CD84-7	Sand Mountain	1303	14.64	0.70741
CL-4240156	BR84-7	Trego Hot Spgs.	1254	19.79	0.70793
W-6332	PL89-22	Trego Hot Spgs.	1263	20.66	0.70786
I-9546	PL44b	Trego Hot Spgs.	1258	23.70	0.70796
<b>Dense tufa coatings from above 1308 m</b>					
CAMS-5930	PLPC92-1	Pipeline Canyon	1325	13.94	0.70737
CAMS-5932	PLPC92-3i	Pipeline Canyon	1329	14.28	0.70740
CL-4240160	AV84-2	Adrian Valley	1324	14.67	0.70727
I-9988	WL101	Walker Lake	1330	15.48	0.70723
I-9325	PL20	Terraced Hills	1311	15.75	0.70737
USGS-2169	BR85-1	Trego Hot Spgs.	1308	16.11	0.70739
<b>Sucrosic tufa (dolomite)</b>					
CAMS-5773	PLBT93-1d	Blanc Tetons	1159	13.30	0.70717
CAMS-4421	PLBT92-d2a	Blanc Tetons	1160	13.69	0.70705
<b>Young dense laminated tufa</b>					
CAMS-5905	PLBT93-1a	Blanc Tetons	1159	10.22	0.70611
LDGO-1748b	PL90-1b	Blanc Tetons	1163	10.62	0.70597
CAMS-5772	PLBT93-1c	Blanc Tetons	1159	11.38	0.70637
<b>Encrusting tufa</b>					
CAMS-5725	BT91-9	Blanc Tetons	1175	1.39	0.70545
CAMS-5727	BT91-7	Blanc Tetons	1168	1.98	0.70548
CAMS-5728	BT91-6	Blanc Tetons	1168	3.00	0.70556
CAMS-5729	BT91-4	Blanc Tetons	1166	5.23	0.70581
<b>Tufas associated with existing springs</b>					
CAMS-5929	PLND92-3	Needles Rocks	1171		0.70506