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Short Paper

Late Pleistocene and late Holocene lake highstands in the Pyramid Lake subbasin of Lake Lahontan, Nevada, USA

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Abstract

Shoreline geomorphology, shoreline stratigraphy, and radiocarbon dates of organic material incorporated in constructional beach ridges record large lakes during the late Pleistocene and late Holocene in the Pyramid Lake subbasin of Lake Lahontan, Nevada, USA. During the late Holocene, a transgression began at or after 3595 ± 35 ^{14}C yr B.P. and continued, perhaps in pulses, through 2635 ± 40 ^{14}C yr B.P., resulting in a lake as high as 1199 m. During the latest Pleistocene and overlapping with the earliest part of the Younger Dryas interval, a lake stood at approximately 1212 m at 10,820 ± 35 ^{14}C yr B.P. and a geomorphically and stratigraphically distinct suite of constructional shorelines associated with this lake can be traced to 1230 m. These two lake highstands correspond to periods of elevated regional wetness in the western Basin and Range that are not clearly represented in existing northern Sierra Nevada climate proxy records.

Keywords: Pyramid Lake; Lake Lahontan; Shorelines; Holocene; Younger Dryas

Introduction

Lake Lahontan receded abruptly from its most recent highstand at ~13,000–13,600 ^{14}C yr B.P. (Adams and Wesnousky, 1998; Benson and Thompson, 1987; Benson et al., 1995; Thompson et al., 1986), leaving behind smaller subbasin lakes in the western Great Basin of North America (Fig. 1). Histories of the latest Pleistocene and Holocene post-Lahontan high lake levels are important for studies of active tectonics, archaeology, and paleoclimate. Here, we present observations bearing on the magnitude and timing of two significant post-highstand lake transgressions in the Pyramid Lake subbasin of Lake Lahontan (Fig. 1), and briefly compare our findings to previously published post-highstand Lahontan lake-level curves and other regional paleoclimate indicators.

Geological observations

Four distinct sets of constructional lacustrine shorelines are preserved in the Pyramid Lake subbasin at the mouth of the Truckee River near Nixon, Nevada (Fig. 2). The lowest, youngest, and best-preserved shorelines (labeled HS, Fig. 2B) occur below 1185 m and reflect historical (1870–1890 A.D.) lake levels (Harding, 1965; Jones, 1933). The oldest and highest elevation shorelines (labeled HR, Fig. 2B) extend basinward concentrically from the ~1337-m, 13,100 ^{14}C yr B.P. highstand and are characterized by broad, often discontinuous crests, deep dissection, locally thick eolian and alluvial cover, and abundant surficial and in situ tufa. Shoreline set HR probably represents recession from the ~1337-m highstand. Our focus here is on two sets of constructional shorelines (labeled A and B in Fig. 2B) situated between the historical (HS) and highstand recessional (HR) shorelines (Fig. 2B).

Shoreline set A extends from 1185 to 1199 m in elevation (Fig. 2B) and is characterized by sharp, continuous crests, minor eolian cover, lack of in situ tufa, and low levels of

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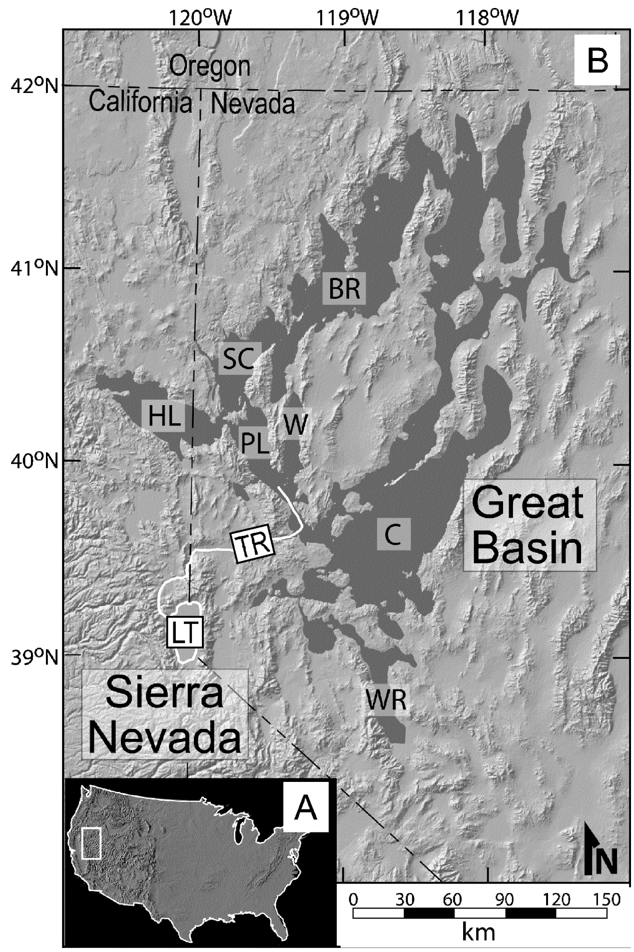

Figure 1. (A) Location of study area in western United States (base from Thelin and Pike, 1991). (B) Map of Lake Lahontan subbasins. Maximum extent of Lake Lahontan in dark grey (modified from Reheis, 1999). Subbasins shown are PL—Pyramid Lake, W—Winnemucca, HL—Honey Lake, SC—Smoke Creek, BR—Black Rock, C—Carson, WR—Walker. Lake Tahoe (LT) and the Truckee River (TR) store and deliver Sierran runoff into the Pyramid subbasin.

channel dissection. To place bounds on the age of the lake transgression responsible for shoreline set A, we excavated a trench (location T1 in Fig. 2) across the lowest continuous beach ridge of the set (crest elevation = 1187 m; all elevations reported here were surveyed by total station and survey-grade GPS receivers with respect to local second-order vertical benchmarks and are accurate to ± 0.1 m). The trench (Fig. 3) exposed lacustrine gravels and sands (Units 2a–2c) deposited on debris flow deposits (Unit 1). Detrital charcoal, probably derived from wildfires upslope and reworked during deposition of the debris flow (e.g., Meyer et al., 1995), was collected from the uppermost portion of Unit 1. Accelerator Mass Spectrometry (AMS) radiocarbon dates of the charcoal place a maximum bound on the age of the debris flow deposit of 4235 ± 40 ^{14}C yr B.P. (sample PLLAC-1187-C1, Fig. 3; Table 1), and thus the rise in lake level responsible for deposition of the lacustrine gravels of Unit 2 did not occur until after this time. A weak soil developed on the buried debris flow deposit (Unit 1) implies an interval of alluvial fan surface stability and subaerial exposure prior to the lake transgression, consistent with middle Holocene drought conditions in the Pyramid Lake/Lake Tahoe system (Benson et al., 2002).

Three distinct packages of lacustrine sands and gravels form the 1187 m beach ridge (Units 2a–2c; Fig. 3). The lowermost package (Unit 2a) consists of lakeward-dipping, low-angle cross-sets (Unit 2a) with a thin (1–3 cm) discontinuous zone of carbonate-cemented beachrock at its base. A package exhibiting steeper, tangential cross-sets dipping away from the lake (Unit 2b) unconformably overlies Unit 2a. We interpret Unit 2b to represent beach backsets formed during landward migration of the surface beach ridge. It is unknown if Unit 2b was deposited immediately after Unit 2a or, alternatively, if the lake first deposited Unit 2a, transgressed to 1199 m, and then deposited Unit 2b during recession from 1199 m. The surface layer, Unit 2c, is a bioturbated portion of Units 2a and 2b with a silty matrix supporting very weak soil development.

Gastropod shells are present throughout the lacustrine sands and gravels of Trench T1 (Units 2a–2c), with nearly all intact and showing no signs of significant transport (Fig. 3). Lacustrine gastropod shells (sp. *Pyrgulopsis nevadensis*; Saxon Sharpe, Desert Research Institute, personal communication) collected from the base of the lacustrine gravels (Unit 2a) yielded an average AMS date of 3595 ± 35 ^{14}C yr B.P. (sample PLLAC-1187-G1; Fig. 3; Table 1). Modern radiocarbon dates from Pyramid Lake reflect a ~500-year ^{14}C reservoir effect (Broecker and Orr, 1958). A ~600-year ^{14}C reservoir effect in the Pyramid subbasin has been inferred for 0.9–3.1 ^{14}C yr B.P. on the basis of unspecified paleomagnetic secular variation features from a piston core (Benson et al., 2002). Because sp. *Pyrgulopsis* may incorporate ^{14}C-deficient groundwater during growth (Brennan and Quade, 1997) and this may yield artificially older ^{14}C ages, and because changes in the reservoir effect in the Pyramid subbasin through time are not yet established, we do not apply a reservoir correction but instead interpret the radiocarbon age of the gastropods as a maximum estimate of their time of death. Application of a reservoir correction would result in a younger age for the gastropods. Taken together, the stratigraphy, sedimentology, and radiocarbon dates from this trench provide evidence for a late Holocene lake transgression at 1187 m elevation after 4235 ± 40 ^{14}C yr B.P., the maximum age of the buried alluvial fan surface, with a lake present at this elevation at or after 3595 ± 35 ^{14}C yr B.P., the maximum age of gastropods at the base of the lacustrine deposit.

Constructional shoreline deposits of shoreline set A are also exposed in a quarry wall at 1195 m (Fig. 4; location P1 on Fig. 2A). Detrital charcoal, reworked and deposited in lacustrine interbedded gravels and sands, limits shoreline emplacement to after 2635 ± 40 ^{14}C yr B.P. This beach ridge is higher in elevation, yet apparently younger than the base of the beach ridge at 1187 m, and raises the possibility that shoreline set A represents multiple transgressions

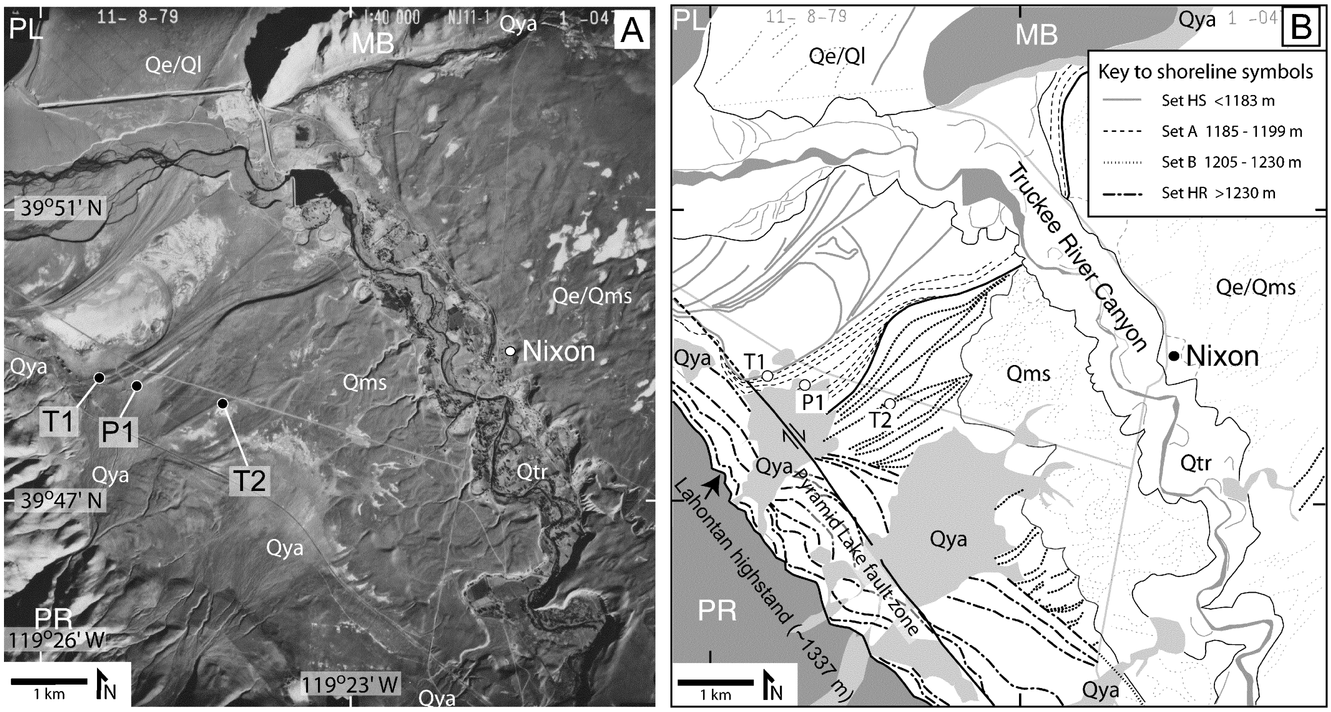

Figure 2. (A) Vertical, low sun angle airphoto showing shorelines in the Pyramid subbasin. T1—Trench 1 at 1187 m (Fig. 3), P1—Pit 1 (quarry exposure) at 1195 m (Fig. 4); T2—Trench 2 at 1212 m (Fig. 5). (B) Generalized surficial geologic map of area in adjacent airphoto. Qtr—Truckee River fluvial deposits and channels; Qe—eolian cover; Ql—undifferentiated lacustrine deposits; Qms—Truckee River meander surface; Qya—post-Lahontan highstand alluvium; PR—Pah Rah Mountains; MB—Marble Bluff. Shoreline sets HS, A, B, and HR discussed in text.

between 1185 and 1199 m during the late Holocene. If this is the case, erosional unconformities present in the lacustrine gravels (Unit 2) of the trench at 1187 m (Fig. 3) may represent significant intervals between repeated rising and falling late Holocene lake levels. Alternatively, the radiocarbon age obtained from the sp. *Pyrgulopsis* gastropods in the 1187 m trench (Fig. 3; Table 1) may be greater than their actual age due to the incorporation of ^{14}C-deficient groundwater (e.g., Brennan and Quade, 1997). Although our data do not fully define the late Holocene lake level curve, dates from the 1187 m trench (Fig. 3) and the 1195 m quarry (Fig. 4), when combined with geomorphic and stratigraphic correlations defining shoreline set A (Fig. 2), indicate a significant late Holocene lake stand during ca. 3600–2600 ^{14}C yr B.P. that reached an elevation of 1199 m.

The older and higher shoreline set B extends from 1205 to 1230 m in elevation (Fig. 2) and is characterized by rounder and less continuous berm crests, thicker eolian cover, more extensive back-barrier playas, and moderately denser and deeper channel dissection than the lower shoreline set A (Fig. 2). Tufa is present only as abundant reworked clasts both on the surface and in trench exposure of shoreline set B. Stratigraphic relationships constrain the relative timing of shoreline sets A, B, and HR: an

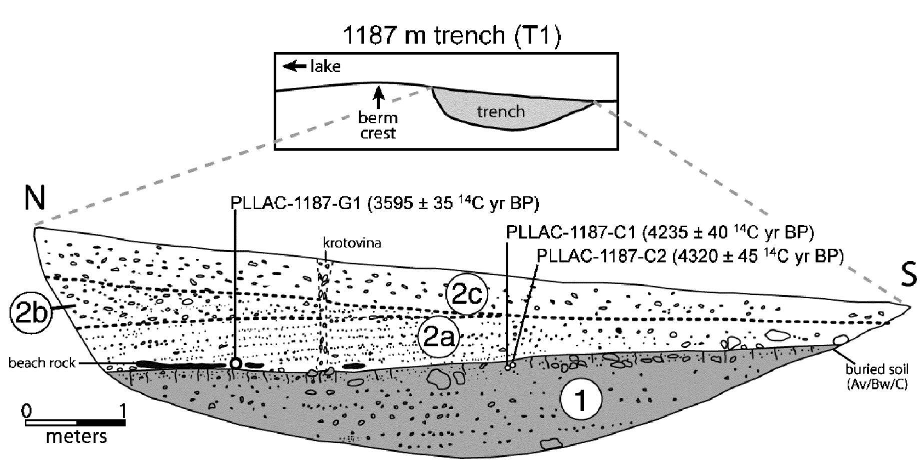

Figure 3. Trench log of Trench 1, 1187 m constructional beach ridge (see location on Fig. 2). Unit 1—poorly sorted debris flow deposit with weak vesicular A (Av) and cambic B (Bw) soil horizons formed on the parent material (C). Units 2a–2c are lacustrine sands and gravels; subdivisions and dated organic material discussed in text. Krotovina is a sediment-filled burrow.

Table 1
Radiocarbon samples

Sample	Sample material	CAMS[a] number	^{14}C age[b] $\pm$ 1σ	δ^{13}C[c]	Calendar age[d] (cal yr B.P. $\pm$ 2σ)
PLLAC-1187-C1	detrital charcoal	88191	4235 $\pm$ 40	−25	4630–4870
PLLAC-1187-C2	detrital charcoal	90557	4320 $\pm$ 45	−25	4830–5030
PLLAC-1187-G1	gastropod test	93340	3595 $\pm$ 35	−1.96	3730–4060
PLLAC-1195-C1	detrital charcoal	81201	2635 $\pm$ 40	−25	2710–2850
PLLAC-1212-G1	pelecypod test	90412	10,820 $\pm$ 35	−8.2	12,640–13,100

[a] Samples processed and AMS ^{14}C measurement performed at Center for Accelerator Mass Spectrometry (CAMS) at Lawrence Livermore National Laboratory.
[b] Using Libby half-life of 5568 yr.
[c] Values are assumed according to Stuiver and Polach (1977) when given without decimal places.
[d] Dendrochronologically calibrated ages calibrated with (Stuiver and Reimer, 1993); range is full range of all intercepts.

abandoned meander surface of the Truckee River (Qms) is overlain by shoreline set A but in turn cuts shoreline set B (Fig. 2B). Additionally, shorelines of set B are inset at nearly right angles into the highest, oldest recessional (HR) shorelines (Fig. 2B), implying dissection of the HR shorelines by a north-flowing Truckee River before the rise to shoreline set B. We excavated Trench 2 across a broad and prominent constructional shoreline at 1212 m to place bounds on the age of shoreline set B (Fig. 5). An intact, nacreous freshwater clam shell obtained from the base of exposed lacustrine sands and gravels returned an AMS radiocarbon age of 10,820 $\pm$ 35 ^{14}C yr B.P. (sample PLLAC-1212-G1; Fig. 5, Table 1). The articulated and relatively undamaged nature of the clam shell indicates that it underwent limited transport prior to deposition. Because the radiocarbon age of the shell may overestimate the actual time since death of the clam due to an unquantified reservoir effect, and because the shell appears to have undergone limited transport, the age of the clam shell provides a maximum age of 10,820 $\pm$ 35 ^{14}C yr B.P. for a 1212-m lake in the Pyramid Lake subbasin. Based on geomorphic and stratigraphic considerations, the lake associated with the 1212-m beach ridge reached a maximum elevation of 1230 m (Fig. 2B). Multiple packages of beach gravels separated by erosional unconformities lie above the clam shell in Trench 2 (Fig. 5), raising the possibility that multiple transgressions and regressions occurred after emplacement of the clam shell at 10,820 $\pm$ 35 ^{14}C yr B.P.

Discussion

Late Holocene lake stand

AMS radiocarbon ages of organic material incorporated into lacustrine deposits record a late Holocene lake stand in the Pyramid Lake subbasin of greater size than previously recognized. The lake stood at 1187 m elevation at or after 3595 $\pm$ 35 ^{14}C yr B.P. and 1195 m elevation at or after 2635 $\pm$ 40 ^{14}C yr B.P. (Figs. 3 and 4). Geomorphic and

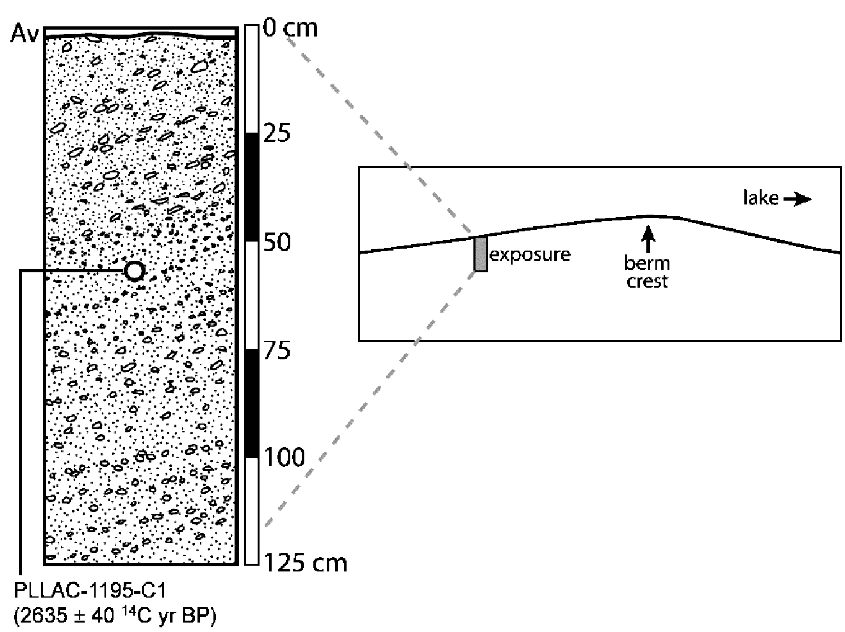

Figure 4. Generalized sketch of quarry exposure P1 at 1195 m (see location in Fig. 2) showing gently to moderately dipping lacustrine sand and gravel packages and location of reworked detrital charcoal. Av—Vesicular silt cap.

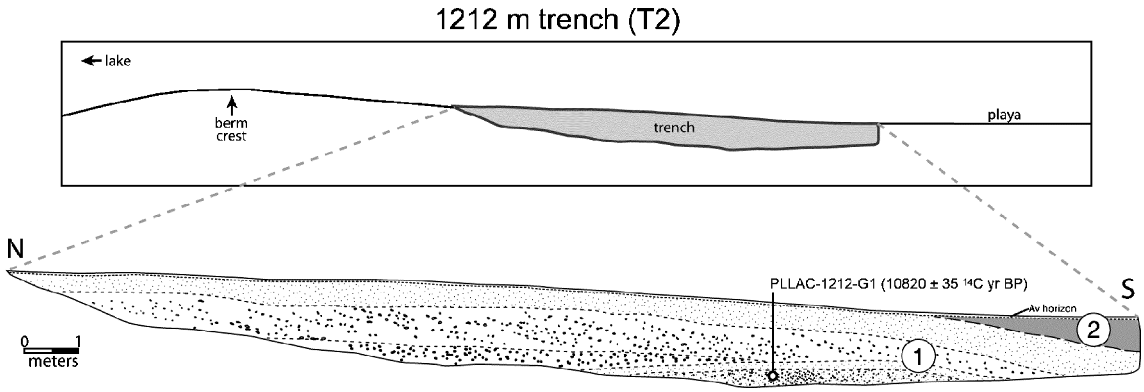

Figure 5. Trench log of Trench 2, 1212 m constructional beach ridge (see location in Fig. 2). Unit 1—lacustrine sands and gravels; Unit 2—palustrine silt and sand deposited behind the beach berm. Dated organic material discussed in text.

stratigraphic shoreline correlations suggest that this late Holocene lake extended to 1199 m (Fig. 2), higher than the previously proposed late Holocene elevation limit of 1183 m (Benson et al., 1995, 2002; Born, 1972; Lagoni, 1985), and was thus fully integrated with neighboring Winnemucca Lake (Fig. 6). The timing of the late Holocene lake we observe corresponds well to the ~3500–2000 ^{14}C yr B.P. Pyramid Lake subbasin lake cycle previously identified by Born (1972) based on radiocarbon dates of wood associated with Truckee River deltaic deposits. Cores from Pyramid Lake show a decrease in total inorganic carbon and δ^{18}O beginning at ~3375 ^{14}C B.P., consistent with increasing

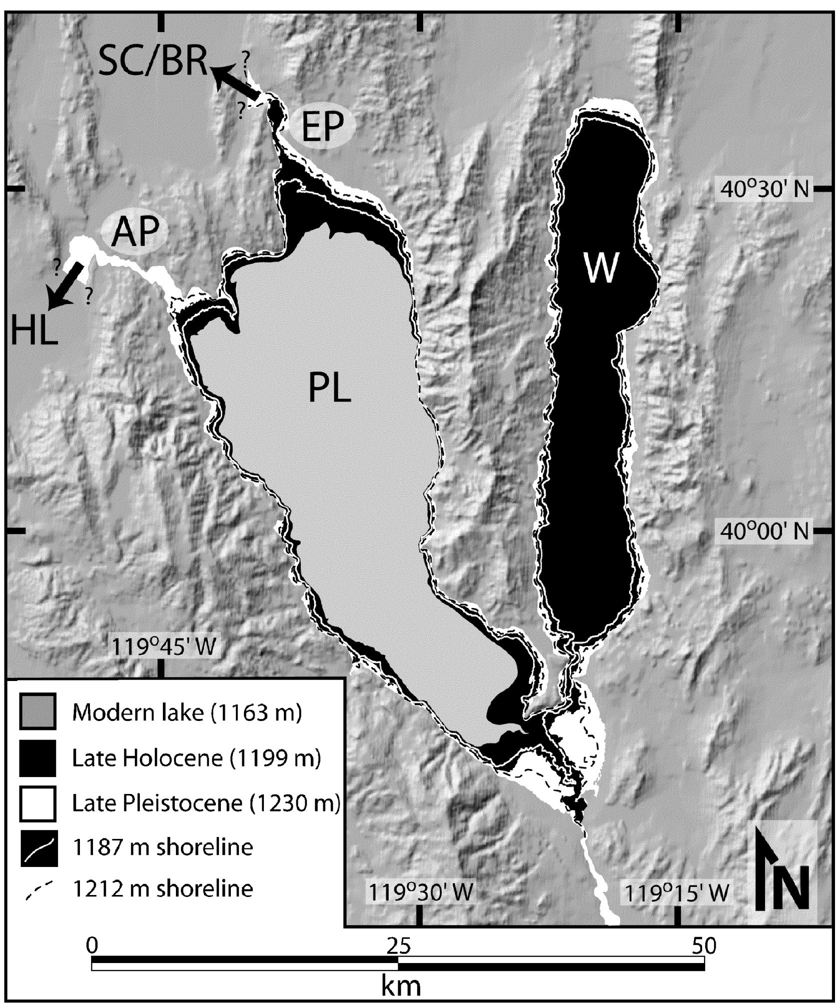

Figure 6. Map of shorelines and corresponding lake extents discussed in text. Subbasins are PL—Pyramid Lake, W—Winnemucca, SC/BR—Smoke Creek/Black Rock, HL—Honey Lake. EP—Emerson Pass (1207 m), AP—Astor Pass (1222 m). Dark arrows show spill over sills when lake levels are higher than sill elevations.

Truckee River discharge and increasing lake size around this time (Benson et al., 2002); unfortunately, the core record is absent for ~3200 to ~2600 ^{14}C B.P. Mensing et al. (2004) measured pollen concentrations from this same set of cores and infer a shift to a relatively moist phase in the Pyramid subbasin spanning ~3500 to ~3200 ^{14}C B.P.

The Pyramid Lake subbasin is the terminus for the Truckee River (Fig. 1) and lake levels in the basin strongly reflect climatic conditions in the northern Sierra Nevada. Late Holocene (Neoglacial) glacial extents in the Sierra Nevada appear to have been minimal (Clark and Gillespie, 1997; Konrad and Clark, 1998), yet numerous studies report increased late Holocene wetness in the western Great Basin roughly coinciding with the late Holocene transgression in the Pyramid Lake subbasin (e.g., Hattori, 1982; Stine, 1990; Wigand, 1987; Wigand and Mehringer, 1985). A large, long-lived lake or series of lakes in the Pyramid Lake and Winnemucca subbasins without corresponding significant Sierran glacial advances during the late Holocene implies relatively wetter, but not colder, conditions than present day during ca. 3600–2600 ^{14}C yr B.P. These conditions might have reflected an increased frequency of extremely large winter floods (e.g., Enzel et al., 1989) or increased summer precipitation due to an unusual northward limit of the North American monsoon (Adams and Comrie, 1997; Harvey et al., 1999).

Late Pleistocene/Younger Dryas lake stand

Russell (1885) recognized that an erosional platform at ~1207 m (his Thinolite Terrace) recorded an important lake stand in the Pyramid lake subbasin. Benson et al. (1990, 1992, 1995) traced a broad, wave-cut erosional surface from 1207 to 1225 m in elevation and inferred a Younger Dryas (approximately 11,000–10,000 ^{14}C yr B.P.) aged lake stand associated with this feature based on the absence of tufa on the erosional platform, rock varnish dates from boulders at 1220 m, and radiocarbon dates of laminated tufa formed underwater at 1159–1205 m elevation. By dating organic material incorporated into a constructional beach ridge, we find direct evidence of a 1212-m lake at 10,820 ± 35 ^{14}C yr B.P. in the Pyramid Lake subbasin (Figs. 2 and 6). The suite of constructional shorelines associated with this lake stand extends to 1230 m elevation. At its maximum extent, this lake would have spilled into, and possibly inundated, the adjacent Honey Lake and Smoke Creek/Black Rock basins (Fig. 6). The maximum lake elevation of 1230 m is consistent with the upper allowable limit of lake elevation after 12,070 ± 210 ^{14}C yr B.P. as constrained by dated soluble packrat middens in adjacent Winnemucca subbasin (Thompson et al., 1986), and with wavecut terraces in the Truckee River Canyon at ~1230 m elevation that were formed between approximately 12,900 and 7000 ^{14}C yr B.P. (Smoot, 1993).

The timing of the 1205–1230 m latest Pleistocene lake in the Pyramid lake subbasin does not appear to be synchronous with other regional post-Lahontan paleolake highstands. Pluvial Lake Chewaucan in southern Oregon experienced a late Pleistocene highstand at ~11,500–12,000 ^{14}C yr B.P. (Licciardi, 2001), significantly earlier than the latest Pleistocene highstand in the Pyramid Lake subbasin. Owens Lake in southeastern California experienced multiple oscillations in lake level between ~13,000 and 9000 ^{14}C yr B.P. (Benson, 1999). These oscillations are not readily compared to the Pyramid subbasin record due to uncertainties in the Owens Lake core age control (Benson, 1999). The 10,820 ± 35 ^{14}C yr B.P. age of the 1212 m lacustrine exposure in the Pyramid subbasin indicates that a large lake was present near the beginning of the Younger Dryas chronozone (approximately 11,000–10,000 ^{14}C yr B.P.) but the relationship between the Younger Dryas interval and the latest Pleistocene highstand in the Pyramid subbasin is not clear. Non-glacial climate proxies from the southern Sierra Nevada suggest a return to slightly cooler and wetter conditions during the Younger Dryas interval (Porinchu et al., 2003), but melting of the Sierran Recess Peak glaciers was complete by approximately 11,200 ± 70 ^{14}C yr B.P. (Clark and Gillespie, 1997). When considered together, post-Lahontan highstand paleolake histories and the Sierran glacial chronology suggest that responses to climate forcing following the Last Glacial Maximum in the Western Great Basin were spatially and temporally complex (e.g., Benson, 1999; Hostetler and Bartlein, 1999). It remains that the 1205–1230 m latest Pleistocene lake shorelines in the Pyramid Lake subbasin reflect very high levels of sustained northern Sierran runoff not clearly observed in existing paleoclimate proxies.

Conclusions

Shoreline geomorphology, shoreline stratigraphic position, and radiocarbon dates of organic material obtained from trench and quarry exposures provide evidence for two significant post-Lahontan highstand (~13,100 ^{14}C yr B.P.) lake transgressions in the Pyramid Lake subbasin. The data do not define a continuous lake level curve, but instead provide point measurements of lake surface elevations with time. In the late Holocene, a lake occupied 1187 m at ~3595 ± 35 ^{14}C yr B.P. and 1195 m at ~2635 ± 40 ^{14}C yr B.P. The late Holocene transgression reached an elevation of 1199 m, higher than previously inferred, and created a lake that fully integrated the Pyramid Lake and Winnemucca Lake subbasins. During the latest Pleistocene and overlapping with the earliest portion of the Younger Dryas chronozone, a lake filled the Pyramid Lake subbasin to 1212 m at 10,820 ± 35 ^{14}C yr B.P. and the suite of shorelines associated with this lake stand can be traced up to 1230 m. At its maximum, this lake would have spilled into the Winnemucca, Smoke Creek/Black Rock, and Honey Lake subbasins and required considerable effective precipitation for its formation and maintenance.

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References

Adams, D.K., Comrie, A.C., 1997. The North American monsoon. Bulletin of the American Meteorological Society 78, 2197–2213.

Adams, K.D., Wesnousky, S.G., 1998. Shoreline processes and the age of the Lake Lahontan highstand in the Jessup embayment, Nevada. Geological Society of America Bulletin 110, 1318–1332.

Benson, L., 1999. Records of millennial-scale climate change from the Great Basin of the Western United States. In: Clark, P.U., Webb, R.S., Keigwin, L.D. (Eds.), Mechanisms of Global Climate Change at Millennial Time Scales. Geophysical Monograph, vol. 112. American Geophysical Union, Washington, D.C., pp. 203–225.

Benson, L.V., Thompson, R.V., 1987. Lake level variation in the Lahontan basin for the past 50,000 years. Quaternary Research 28, 69–85.

Benson, L.V., Currey, D.R., Dorn, R.I., Lajoie, K.R., Oviatt, C.G., Robinson, S.W., Smith, G.I., Stine, S., 1990. Chronology of expansion and contraction of four Great Basin lake systems during the past 35,000 years. Palaeogeography, Palaeoclimatology, Palaeoecology 78, 241–286.

Benson, L., Currey, D., Lao, Y., Hostetler, S., 1992. Lake-size variations in the Lahontan and Bonneville basins between 13,000 and 9000 ^{14}C yr B.P. Palaeogeography, Palaeoclimatology, Palaeoecology 95, 19–32.

Benson, L., Kashgarian, M., Rubin, M., 1995. Carbonate deposition, Pyramid Lake subbasin, Nevada: 2. Lake levels and polar jet stream positions reconstructed from radiocarbon ages and elevations of carbonates (tufas) deposited in the Lahontan basin. Palaeogeography, Palaeoclimatology, Palaeoecology 117, 1–30.

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

Born, S.M., 1972. Late Quaternary history, deltaic sedimentation, and mudlump formation at Pyramid Lake. University of Nevada, Desert Research Institute, Nevada, 97 p.

Brennan, R., Quade, J., 1997. Reliable Late-Pleistocene stratigraphic ages and shorter groundwater travel times fro‘m ^{14}C in fossil snail from the southern Great Basin. Quaternary Research 47, 329–336.

Broecker, W.S., Orr, P.C., 1958. Radiocarbon chronology of Lake Lahontan and Lake Bonneville. Geological Society of America Bulletin 69, 1009–1032.

Clark, D.H., Gillespie, A.R., 1997. Timing and significance of late-glacial and Holocene cirque glaciation in the Sierra Nevada, California. Quaternary International 38–9, 21–38.

Enzel, Y., Cayan, D.R., Anderson, R.Y., Wells, S.G., 1989. Atmospheric circulation during Holocene lake stands in the Mojave Desert: evidence of regional climate change. Nature 341, 44–47.

Harding, S.T., 1965. Recent variations in the water supply of the western Great Basin: Water Resources Center Archives, no. 16. University of California, 226 p.

Harvey, A.M., Wigand, P.E., Wells, S.G., 1999. Response of alluvial fan systems to the late Pleistocene to Holocene climatic transition: contrasts between the margins of pluvial Lakes Lahontan and Mojave, Nevada and California, USA. Catena 36, 255–281.

Hattori, E.M., 1982. The archaeology of Falcon Hill, Winnemucca Lake, Washoe County, Nevada. Nevada State Museum anthropological papers, vol. 18.

Hostetler, S.W., Bartlein, P.J., 1999. Simulation of the potential responses of regional climate and surface processes in western North America to a canonical Heinrich event. In: Clark, P.U., Webb, R.S., Keigwin, L.D. (Eds.), Mechanisms of Global Climate Change at Millennial Time Scales. Geophysical Monograph, vol. 112. American Geophysical Union, Washington, D.C., pp. 313–327.

Jones, J.C., 1933. Itinerary, Reno to Pyramid Lake and return, in Middle California and western Nevada (Excursion C-1). In: Jenkins, O.P. (Ed.), International Geological Congress, XVI session, Guidebook, vol. 16. U.S. Gov. Print. Off., Washington, DC, pp. 102–108.

Konrad, S.K., Clark, D.H., 1998. Evidence for an early neoglacial glacier advance from rock glaciers and lake sediments in the Sierra Nevada, California, USA. Arctic and Alpine Research 30, 272–284.

Lagoni J.R., 1985. The geomorphology of the Truckee River delta, at Pyramid Lake, Nevada, and implications on the decline of Lake Lahontan [M.S. thesis]: Reno, Nevada, University of Nevada, Reno, 94 p.

Licciardi, J.M., 2001. Chronology of latest Pleistocene lake-level fluctuations in the pluvial Lake Chewaucan basin, Oregon, USA. Journal of Quaternary Science 16, 545–553.

Mensing, S.A., Benson, L.V., Kashgarian, M., Lund, S., 2004. A Holocene pollen record of persistent droughts from Pyramid Lake, Nevada, USA. Quaternary Research 62, 29–38.

Meyer, G.A., Wells, S.G., Jull, A.J.T., 1995. Fire and alluvial chronology in Yellowstone National Park: Climatic and intrinsic controls on Holocene geomorphic processes. Geological Society of America Bulletin 107, 1211–1230.

Porinchu, D.F., MacDonald, G.M., Bloom, A.M., Moser, K.A., 2003. Late Pleistocene and early Holocene climate and limnological changes in the Sierra Nevada, California, USA inferred from midges (Insecta: Diptera; Chironomidae). Palaeogeography, Palaeoclimatology, Palaeoecology 198, 403–422.

Reheis, M., 1999. Extent of Pleistocene Lakes in the Western Great Basin: USGS Miscellaneous Field Studies Map MF-2323.

Russell, I.C., 1885. Geological history of Lake Lahontan: a Quaternary lake of northwestern Nevada. U.S. Geological Survey Monograph 11, 288.

Smoot, J.P., 1993. Field Trip Guide: Quaternary-Holocene lacustrine sediments of Lake Lahontan, Truckee River Canyon north of Wadsworth, Nevada: USGS Open-File Report 93-689.

Stine, S., 1990. Late Holocene fluctuations of Mono Lake, Eastern California. Palaeogeography, Palaeoclimatology, Palaeoecology 78, 330–381.

Stuiver, M., Polach, H.A., 1977. Discussion: reporting of 14C data. Radiocarbon 19 (3), 355–363.

Stuiver, M., Reimer, P.J., 1993. Extended C-14 database and revised CALIB 3.0 C-14 age calibration program. Radiocarbon 35 (1), 215–230.

Thelin, G.P., Pike, R.J., 1991. Landforms of the Conterminous United States—A Digital Shaded-Relief Portrayal: U.S. Geological Survey Miscellaneous Investigations Series Map I-2206.

Thompson, R.S., Benson, L., Hattori, E.M., 1986. A revised chronology for the last Pleistocene lake cycle in the central Lahontan Basin. Quaternary Research 25, 1–9.

Wigand, P.E., 1987. Diamond pond, Harney County, Oregon: vegetation history and water table in the Eastern Oregon Desert. Great Basin Naturalist 47, 427–458.

Wigand, P.E., Mehringer, P.J., 1985. Pollen and seed analysis, chapter 9. In: Thomas, D.H. (Ed.), The Archaeology of Hidden Cave, Nevada, Anthropological papers of the American Museum of Natural History, vol. 61, pp. 108–124.