



Paleohydrology of China Lake basin and the context of early human occupation in the northwestern Mojave Desert, USA



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ABSTRACT

Considerable prior research has focused on the interconnected pluvial basins of Owens Lake and Searles Lake, resulting in a long record of paleohydrological change in the lower Owens River system. However, the published record is poorly resolved or contradictory for the period encompassing the terminal Pleistocene (22,000 to 11,600 cal BP) and early Holocene (11,600–8200 cal BP). This has resulted in conflicting interpretations about the timing of lacustrine high stands within the intermediate basin of China Lake, which harbors one of the most extensive records of early human occupation in the western Great Basin and California. Here, we report a broad range of radiocarbon-dated paleoenvironmental evidence, including lacustrine deposits and shoreline features, tufa outcrops, and mollusk, ostracode, and fish bone assemblages, as well as spring and other groundwater-related deposits (a.k.a. “black mats”) from throughout China Lake basin, its outlet, and inflow drainages. Based on 98 radiocarbon dates, we develop independent evidence for five significant lake-level oscillations between 18,000 and 13,000 cal BP, and document the persistence of groundwater-fed wetlands from the beginning of the Younger Dryas through the early Holocene (12,900–8200 cal BP); including the transition from ground-water fed lake to freshwater marsh between about 13,000 and 12,600 cal BP. Results of this study support and refine existing evidence that shows rapid, high-amplitude oscillations in the water balance of the Owens River system during the terminal Pleistocene, and suggest widespread human use of China Lake basin began during the Younger Dryas.

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1. Introduction

The Owens River system once drained almost the entire eastern Sierra Nevada, from Mono Lake to Owens Lake, and extended well into the northern Mojave Desert, through Indian Wells Valley and China Lake basin, Searles and Panamint valleys, finally ending at Lake Manly in Death Valley (Fig. 1; Gale, 1914, 1915; Smith and Street-Perrott, 1983). During the terminal Pleistocene

(22,000–11,600 cal BP), however, the pale-Owens River only connected the intermediate basins of Owens, China, Searles, and Panamint lakes (Benson et al., 1990; Jayko et al., 2008; Smith, 2009; Smith and Street-Perrott, 1983); by the early Holocene (beginning 11,600 cal BP), the river terminated at Owens Lake (Bacon et al., 2006; Smith, 2009; Figure 39, 81–82). Numerous important studies document the fluvial history of the lower Owens River system and have contributed significantly to regional paleohydrological models and evidence for long-term climate change in the southwestern United States (Bacon et al., 2006; Benson, 2004; Benson et al., 1990, 1996, 1997, 1998, 2002; Bischoff et al., 1985; Dorn et al., 1990; Flint and Gale, 1958; Garcia et al., 1993; Jayko et al., 2008; Lin et al., 1998; Orme and Orme, 1993, 2000, 2008; Phillips, 2008; Phillips et al., 1996; Reheis et al., 2014; Smith, 1963, 1968, 1979, 1987, 2009; Smith and Bischoff, 1997; Smith and Street-Perrott, 1983; Stuiver, 1964).

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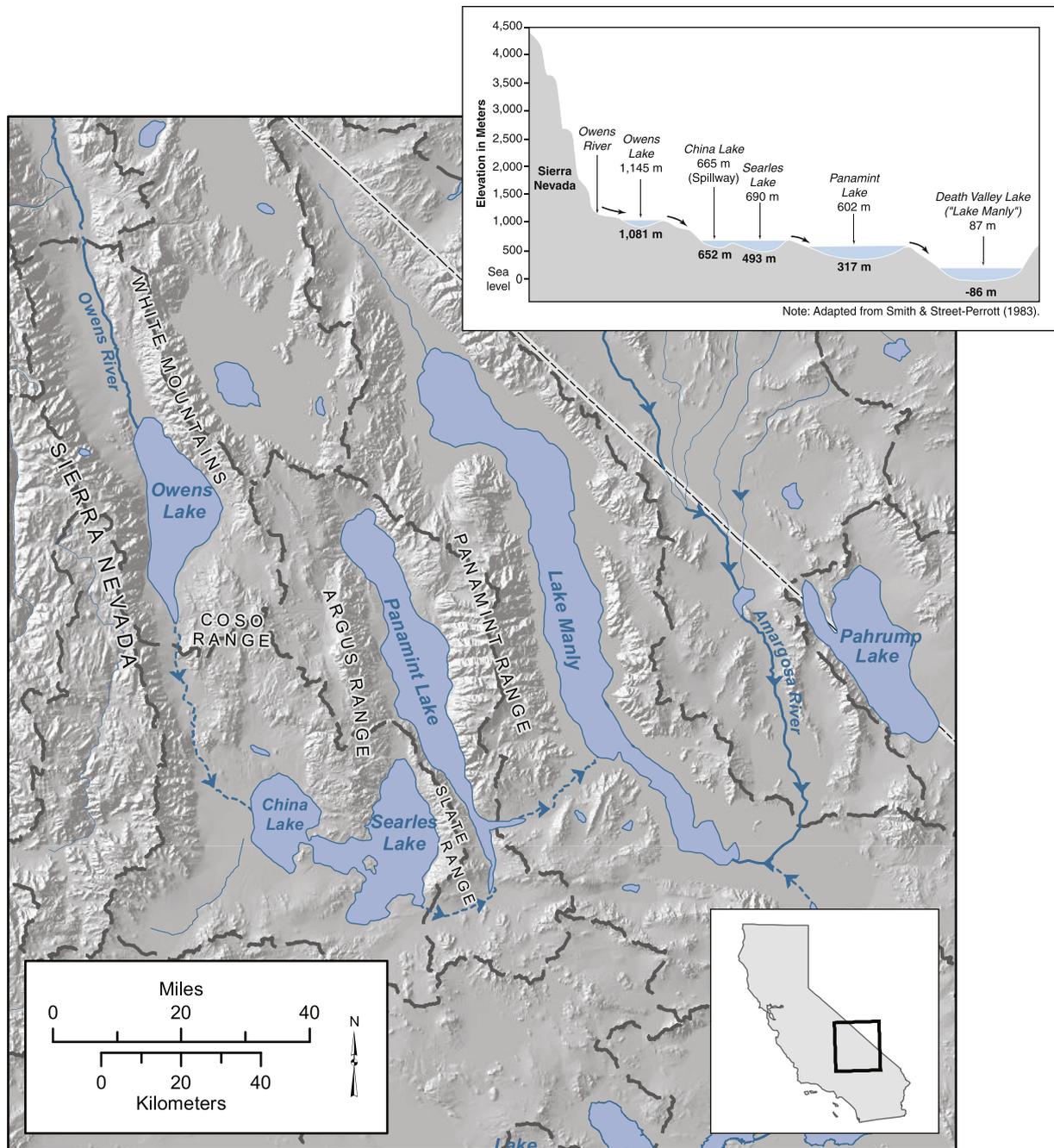


Fig. 1. Hydrologically connected pluvial lake basins in the lower Owens River system.

Despite good evidence for the timing of major lake oscillations in the interconnected basins of the Owens River system, there is poor resolution or conflicting information for the period encompassing the terminal Pleistocene and early Holocene (ca. 22,000–8200 cal BP; c.f., Bacon et al., 2006, 2014; Benson et al., 1990, 1996, 1998; Orme and Orme, 2008; Smith, 2009; Smith et al., 1997). Since overflow from Owens Lake through the lower Owens River would be required to fill Searles Lake and all other downstream basins (Smith, 2009:81–82; Smith and Street-Perrott, 1983:199), the intermediate China Lake basin is well-situated to resolve inconsistencies between the upstream and downstream

hydrological records. Likewise, the comparatively shallow depth of China Lake basin (about 13 m), suggests that lake levels would have responded much more quickly to changes in the regional hydrological balance than the much deeper downstream basins of Searles and Panamint (Smith and Street-Perrott, 1983:Table 10.2).

China Lake basin is also one of very few places in the Mojave Desert that manifests substantial evidence for human occupation during the terminal Pleistocene and early Holocene, with no fewer than 100 surface sites producing diagnostic tools or early obsidian hydration readings characteristic of this time period (Basgall, 2004, 2007; Byrd, 2006, 2007; Davis and Panlaqui, 1978; Giambastiani

and Bullard, 2007; Giambastiani and Sprengeler, 2010; Rosenthal and Ugan, 2013a, 2013b; Rosenthal et al., 2001). Importantly, the remains of extinct Pleistocene fauna are commonly found alongside these human tools (e.g., Basgall, 2007; Davis, 1975, 1982; Davis and Panlaqui, 1978; Davis et al., 1981). Archaeologists have speculated that a pluvial lake and lake-side marshes, or spring seeps, wet meadows, and other riparian habitats were likely an important draw to early human foragers (e.g., Basgall, 2004, 2005; Davis and Panlaqui, 1978; Giambastiani, 2008; Rosenthal et al., 2001; Warren, 2008). Yet little is known about the types of habitats that existed in China Lake basin and the larger Indian Wells Valley during the transition from the Pleistocene to the Holocene, a time of rapid climatic and biological change (e.g., Gillespie et al., 2004). The surficial nature of the archaeological record has also hindered research efforts in the basin. No artifact-bearing stratigraphic contexts suitable for radiocarbon-dating have been identified. As a result, the timing of the earliest human occupation is poorly constrained and the chronological relationship between extinct fauna and human tools is unknown. Moreover, a substantial portion of the terminal Pleistocene and early Holocene archaeological record, as well as the great majority of extinct fauna, occur at elevations in the basin that would have been submerged during pluvial events (e.g., Rosenthal et al., 2001; Warren, 2008), suggesting that these deposits pre- and/or post-date the last lake transgression (e.g., Basgall, 2007; Rosenthal et al., 2001; Warren, 2008).

In this study, we combine new results with existing radiometric, paleobiological, and stratigraphic information from China Lake basin and the outflow channel through Salt Wells Valley to construct an independent lake-level curve, representing the minimum altitude of China Lake (and the coalesced Lake Searles) from approximately 22,000 to 12,000 cal BP. Also documented is the persistence of groundwater seeps, springs, and related wetland habitats in China Lake basin and its inflow drainages from about 12,600 to 9000 cal BP.

1.1. Physical setting

China Lake basin is the depocenter of Indian Wells Valley, an enclosed hydrological sink situated in the northwestern corner of the Mojave Desert along the eastern escarpment of the Sierra Nevada mountain range (Fig. 2). The valley is a down-dropped bedrock basin infilled with as much as 760 m of lacustrine and alluvial sediments (St.-Amand, 1986; Zbur, 1963). It extends for about 56 km north-south and 40 km east-west, covering approximately 1387 square kilometers. Rose Valley adjoins the basin to the northwest, beyond a narrow bedrock constriction at Little Lake. Rose Valley, in turn, is separated from Owens Valley further north by an alluvial sill at the southern end of Owens Lake (Bacon et al., 2006, 2014; Orme and Orme, 1993, 2008).

Surface elevations in Indian Wells Valley range from 652 m above mean sea level (amsl) on the China Lake playa to about 914 m amsl at the top of the alluvial piedmont fringing the adjacent mountain slopes. Sierra Nevada peaks reach between 1830 and 4415 m amsl along the western edge of the valley, creating a significant rain shadow from eastward-moving Pacific storms. The Coso Range to the north exceeds 2500 m amsl, while the Argus Range to the east and El Paso Mountains to the south reach elevations between 1220 and 1830 m amsl. Within Indian Wells Valley, the east-west running White Hills form a hydrological divide between Airport Lake basin on the north and China Lake basin on the south. The White Hills are partly overlain by Pleistocene basalt flows that form prominent flat-topped ridges adjacent to the former channel of the lower Owens River (Duffield and Bacon, 1981; Duffield and Smith, 1978; St.-Amand and Roquemore, 1979; Zbur, 1963).

Indian Wells Valley is structurally controlled by a series of mostly active faults, including the Sierra Nevada Frontal Fault to the west, the Airport Lake and Argus Range faults to the east, the Little Lake Fault to the north-northwest, and the Inyokern Fault to the south (Roquemore, 1981; Zbur, 1963). The valley floor is flanked by a series of broad coalescing Pleistocene-age pediments and Holocene-age alluvial fans. On the western and southern sides of the valley, these low-gradient fans extend for several kilometers into China Lake basin. Along the northwestern edge of the valley, distal portions of the eastward-oriented fans are truncated by a complex of well-defined channels and ephemeral washes that form the paleo-course of the lower Owens River. The largest channels are distinguished by extensive, linear boulder-levees of mixed lithology incorporating both Sierra Nevada granite and basalt from the Coso Range. The size and basin-ward position of these boulder ridges indicate that they developed under very high-energy conditions, possibly as a result of catastrophic outburst floods during the late Pleistocene (e.g., Amos et al., 2013; Bacon et al., 2014). The former river channels are less pronounced as they enter the basin, giving way to a broad delta formation, partially obscured by Holocene-age alluvial fans and aeolian deposits. Remnant anastomosed channel segments are still evident in some locations within the delta plain, but are largely absent on the eastern side of the basin where low dunes and expanses of playa are common. On the southwestern edge of the valley, Little Dixie Wash occupies a broad segmented fan and channels runoff from five eastern Sierra Nevada tributaries including, Freeman Canyon, Cow Heaven Canyon, Sage Canyon, Peak Horse Canyon, and Bird Spring Canyon. Along with the former Owens River, Little Dixie Wash is the only drainage with headwaters in the eastern Sierra Nevada to flow directly into China Lake basin.

In the past, China Lake basin received significant amounts of surface water from the lower Owens River, with only minor contributions from local washes and streams (Smith, 2009; St.-Amand, 1986). When Owens Lake reached its sill elevation of about 1145 m amsl (Bacon et al., 2006; but see Bacon et al., 2014), it overflowed to the lower Owens River through Rose Valley and into Indian Wells Valley and China Lake basin (Fig. 1; Smith and Street-Perrott, 1983). After reaching a depth of approximately 13 m, at a sill altitude of approximately 665 m amsl, China Lake would drain into Searles Valley by way of Salt Wells Valley and Poison Canyon (Benson et al., 1990; Gale, 1914, 1915; Meyer et al., 2011; Smith, 2009; Smith and Street-Perrott, 1983; Warren, 2008). Searles Lake would fill to a depth of approximately 172 m before it coalesced with China Lake to form pluvial Lake Searles. Once Lake Searles reached an altitude of 690 m amsl (Smith and Street-Perrott, 1983), it spilled into Panamint Valley. In turn, Lake Panamint would over-top its sill and flow into Death Valley when it attained a depth of 285 m, at an altitude of about 602 m amsl (Jayko et al., 2008; Smith and Street-Perrott, 1983).

2. Methods

2.1. Radiocarbon

This study reports 80 previously unpublished accelerator mass spectrometry (AMS) dates from samples of organic sediment (bulk organic carbon), tufa (carbonate), and aquatic and semi-aquatic gastropod and pelecypod shells. These data were integrated with 18 previously published AMS and conventional radiocarbon dates from similar material obtained in Salt Wells Valley, China Lake basin, and the wider Indian Wells Valley, including the adjacent watershed of Dove Springs Wash (Fig. 2, #39). The 80 AMS dates reported here were analyzed by three different laboratories, including Beta Analytic Inc. (BETA), the National Ocean Sciences

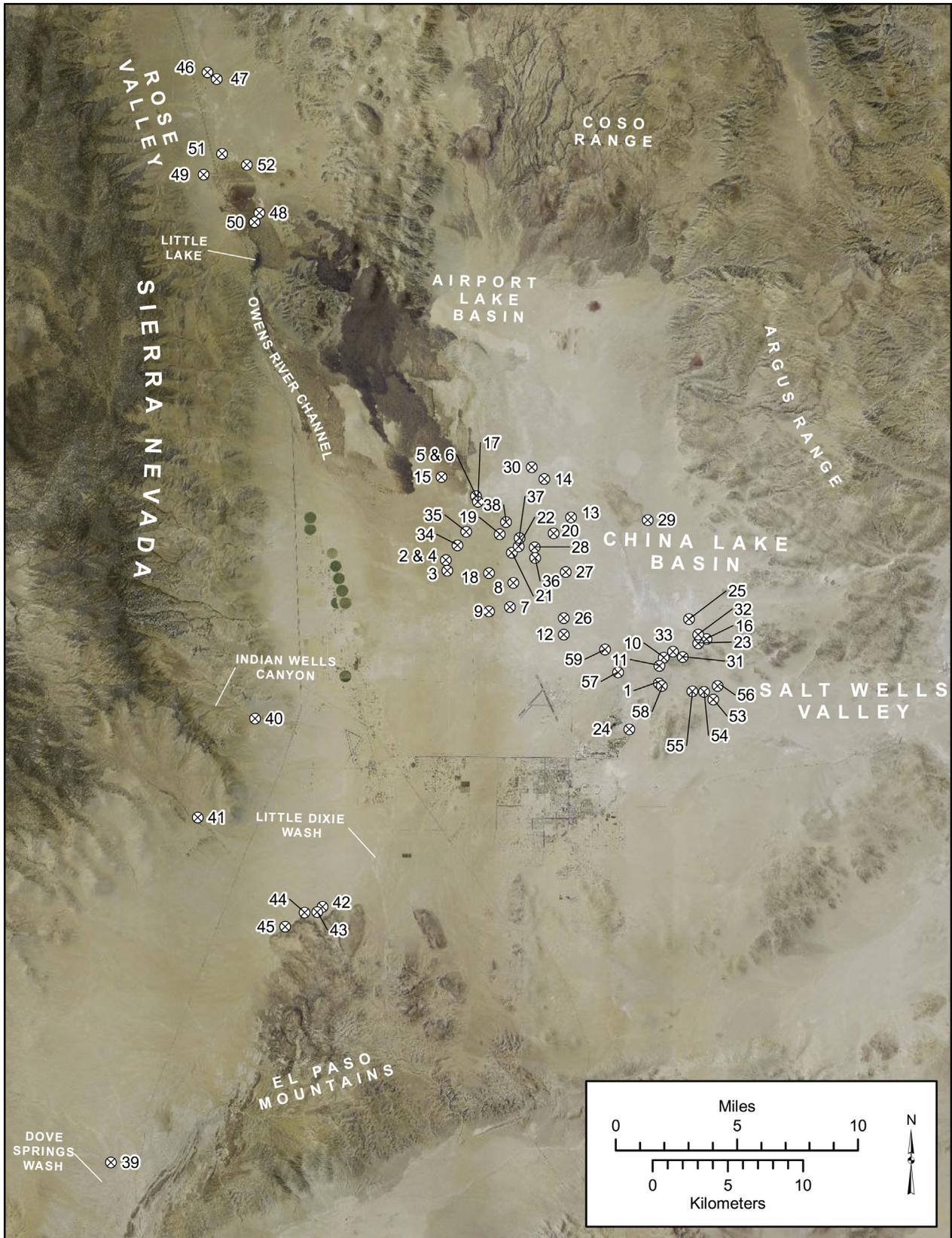


Fig. 2. Indian Wells Valley and adjacent regions showing sample localities in Rose Valley, China Lake Basin, Salt Wells Valley, Little Dixie Wash, Dove Springs Wash and the Eastern Sierra Nevada. Locality numbers are identified in [Tables 1 and 2](#)

Table 1
Radiocarbon dates from mollusks, charcoal, organic sediment, tufa, and bone used in this study.

Fig. 2 #	Locality/Context	Sample Elevation (meters amsl)	Material Dated	Depth (cm bs)		¹⁴ C yr BP	¹³ C/ ¹² C (‰)	Calibrated years BP ^a		Lab No.	Ref.
				Min.	Max.			Median Probability	2-sigma range		
<i>China Lake Basin</i>											
1	Algal Tufa, bedrock knoll W of lake outlet	665.5	carbonate, tufa	0	0	11,440 ± 50	-4.6	13,285	13,155–13,405	Beta-280,683	2
2	Alrite Pit	679.0	<i>Planorbella trivolvis</i> (n = 1)	150	150	10,650 ± 30	n/r ^b	12,635	12,565–12,695	ULN-15D0061	1
3	Baker Borrow Pit, locality 1	679.0	<i>Physella virgata</i> (n = 1)	175	185	9930 ± 90	n/r ^b	11,400	11,200–11,725	ULN-13D0083	1
3	Baker Borrow Pit, locality 3	680.0	<i>Stagnicola</i> sp. (n = 1)	80	100	9510 ± 110	n/r ^b	10,840	10,545–11,175	ULN-13D0082	1
4	Baker Camera Pit	679.3	<i>Planorbella trivolvis</i> (n = 7)	210	210	13,050 ± 40	n/r ^b	15,645	15,385–15,830	ULN-15D0094	1
5	Basalt Ridge, tufa #1	677.6	carbonate, tufa	0	0	13,300 ± 150	n/m	15,985	15,495–16,435	UCLA-1911A	3
5	Basalt Ridge, tufa	677.6	carbonate, tufa	0	0	12,200 ± 120	n/m	14,120	13,760–14,665	UCLA-1911B	3
5	Basalt Ridge, tufa #1	677.6	carbonate, tufa	0	0	12,850 ± 40	n/r ^b	15,315	15,160–15,545	ULN-15D0097	1
6	Basalt Ridge, INY-5825, collection area A	677.6	bulk organic carbon	0	10	10,800 ± 310	-25.0 ^c	12,655	11,760–13,310	GX-03446	3
6	Basalt Ridge, INY-5825, Fagnant collection	675.1	<i>Anodonta</i> sp. (n = 1)	0	0	12,580 ± 90	n/r ^b	14,880	14,350–15,215	ULN-14D0065	1
6	Basalt Ridge, INY-5825, S48/W30.5, stain 1	677.6	bulk organic carbon	37	47	9870 ± 50	-25.1	11,270	11,200–11,395	Beta-170,210	4
6	Basalt Ridge, INY-5825, S48/W30.5, stain 1	677.6	bulk organic carbon	2	6	8390 ± 110	-23.2	9360	9020–9555	Beta-170,208	4
6	Basalt Ridge, INY-5825, S50/W17, buried soil	677.6	bulk organic carbon	35	45	10,010 ± 130	-25.2	11,540	11,230–11,845	Beta-170,209	4
7	Charlie Tower, pit 1	669.5	<i>Planorbella trivolvis</i> (n = 1)	120	120	13,350 ± 25	n/r ^b	16,065	15,900–16,225	ULN-15D0093	1
9	Core 9, 11Cg horizon	658.9	bulk organic carbon	1060	1067	14,610 ± 50	-24.6	17,795	17,620–17,970	Beta-280,680	2
9	Core 9, 6Cg horizon, pale olive silty clay	665.3	bulk organic carbon	396	457	9690 ± 50	-26.3	11,125	11,065–11,225	Beta-280,679	2
10	Dike Lake, SL-01, split sample A	659.6	gastropod	150	167	14,060 ± 50	n/r	17,090	16,865–17,350	I-0?	5
10	Dike Lake, SL-01, split sample B	659.6	gastropod	150	167	12,825 ± 170	n/r	15,295	14,605–15,890	AA-00?	5
10	Dike Lake, upper shell bed, stratum VI	659.6	<i>Valvata humeralis</i> (n = 30)	90	90	14,050 ± 30	n/r ^b	17,075	16,865–17,265	ULN-15D0070	1
10	Dike Lake, lower shell bed, stratum IV	659.5	<i>Valvata humeralis</i> (n = 22)	100	105	14,200 ± 30	n/r ^b	17,290	17,125–17,465	ULN-15D0071	1
10	Dike Lake, south pit, stratum III	659.3	<i>Planorbella trivolvis</i> (n = 1)	105	135	15,500 ± 30	n/r ^b	18,760	18,650–18,855	ULN-15D0069	1
11	Dune Quarry	662.3	<i>Planorbella trivolvis</i> (n = 1)	0	0	12,400 ± 30	n/r ^b	14,455	14,185–14,745	ULN-15D0062	1
12	E.L. Davis, Stake 1, trench 3, stratum A-1	663.2	bulk organic carbon	95	105	10,275 ± 165	-25.0 ^c	12,025	11,390–12,560	GX-03442	3
12	E.L. Davis, Stake 1, trench 3, stratum A-2	663.2	bulk organic carbon	95	105	6775 ± 260	-25.0 ^c	7645	7165–8165	GX-03443	3
12	E.L. Davis, Stake 1, trench 3, stratum B	663.4	bulk organic carbon	175	185	9360 ± 365	-25.0 ^c	10,635	9555–11625	GX-03444	3
26	E.L. Davis, Mammoth #4	663.9	bone, mammoth ivory	0	10+	18,640 ± 4500	-25.0 ^c	22,480	20,080–24,905	UCLA-1800	3
13	Gzap Borrow Pit	665.1	<i>Sphaerium striatinum</i> (n = 1)	25	35	18,100 ± 100	n/r ^b	21,940	21,635–22,255	ULN-14D0063	1
14	Homestead Pit, Darwin Road	668.1	<i>Helisoma newberryi</i> (n = 10)	120	130	>32,800	n/r ^b	–	–	ULN-15D0064	1
15	Horseshoe Tufa #1	684.3	carbonate, tufa	0	0	14,100 ± 70	n/r ^b	17,155	16,895–17,430	ULN-15D0003	1
16	Huge Pit, Knox Road	670.9	<i>Helisoma newberryi</i> (n = 2)	430	430	>32,800	n/r ^b	–	–	ULN-15D0063	1
17	KER-5598, CU 1	666.0	<i>Vorticifex effusa</i> (n = 1)	40	50	16,870 ± 90	n/r ^b	20,345	20,080–20,590	ULN-14D0064	1
18	KER-5611, CU 2	673.0	<i>Sphaerium striatinum</i> (n = 1)	30	40	10,690 ± 90	n/r ^b	12,635	12,520–12,740	ULN-13D0087	1
19	KER-6634, CU 1, 2Ob horizon	673.9	bulk organic carbon	20	30	8990 ± 100	n/r ^b	10,085	9740–10300	ULN-13D0011	7
19	KER-6634, CU 1, 2Ob horizon	673.9	bulk organic carbon	20	30	9290 ± 30	-23.6	10,495	10,395–10,580	Beta-351,614	7
20	KER-6962, CU 1, 2Ob horizon	666.9	bulk organic carbon	22	26	10,050 ± 50	-23.3	11,565	11,320–11,810	Beta-338,055	6
21	KER-6966, CU 1	671.5	<i>Planorbella trivolvis</i> (n = 1)	70	80	10,030 ± 40	-6.2	11,525	11,330–11,720	Beta-345,243	6
22	KER-6968, CU-1	672.8	<i>Sphaerium striatinum</i> (n = 1)	20	30	11,500 ± 50	-2.1	13,350	13,250–13,455	Beta-345,244	6
23	Knox Road Cut	668.4	<i>Valvata humeralis</i> (n = 33)	90	90	28,500 ± 120	n/r ^b	32,500	31,885–32,955	ULN-15D0067	1
24	Lark Seep, N of golf course & Knox Rd	672.4	bulk organic carbon	44	46	10,070 ± 155	n/r	11,655	11,205–12,165	AA-0?	5
25	Lower Playa Cut	658.6	bulk organic carbon	0	10	8750 ± 45	n/r ^b	9735	9575–9905	ULN-15D0098	1
25	Lower Playa Cut	658.6	<i>Anodonta</i> sp. (n = 1)	0	10	10,400 ± 30	n/r ^b	12,270	12,095–12,410	ULN-15D0099	1
25	Lower Playa Cut	658.7	<i>Gyraulus parvus</i> (n = 25)	0	20	10,300 ± 25	n/r ^b	12,070	11,955–12,170	ULN-15D0072	1

Table 1 (continued)

Fig. 2 #	Locality/Context	Sample Elevation (meters amsl)	Material Dated	Depth (cm bs)		¹⁴ C yr BP	¹³ C/ ¹² C (‰)	Calibrated years BP ^a		Lab No.	Ref.
				Min.	Max.			Median Probability	2-sigma range		
27	Mussel Playa West	665.7	<i>Planorbella trivolvis</i> (n = 1)	0	10	12,850 ± 45	n/r ^b	15,320	15,155–15,555	ULN-15D0066	1
28	Mystery Site	668.7	<i>Anodonta</i> sp. (n = 1)	0	5	12,600 ± 25	n/r ^b	14,980	14,760–15,135	ULN-15D0004	1
29	Paxton Ranch, tufa	669.0	carbonate, tufa	0	0	12,950 ± 65	n/r ^b	15,480	15,250–15,730	ULN-15D0005	1
31	SBR-12390, Parcel 18, test unit	660.4	<i>Anodonta</i> sp. (n = 1)	10	20	13,460 ± 80	-2.4	16,200	15,940–16,485	Beta-220,691	8
32	SBR-12391, gully	659.0	<i>Valvata humeralis</i> (n = 6)	10	20	14,350 ± 30	n/r ^b	17,495	17,325–17,635	ULN-15D0068	1
33	SBR-12391, Parcel 16, test unit	658.8	<i>Helisoma trivolvis</i> (n = 1)	10	20	14,390 ± 70	-3.9	17,540	17,295–17,795	Beta-220,692	8
34	TO 39, Loc. 4, China Lake basin	675.4	<i>Stagnicola</i> sp. (n = 1)	0	0	9840 ± 90	n/r ^b	11,270	11,085–11,620	ULN-13D0085	1
35	TO 39, Loc. 1, China Lake basin	675.0	<i>Planorbella trivolvis</i> (n = 1)	0	0	9930 ± 90	n/r ^b	11,400	11,200–11,725	ULN-13D0086	1
36	Tower 7 Borrow Pit, G1 Road	668.4	<i>Gyraulus parvus</i> (n = ~100)	36	36	12,200 ± 25	n/r ^b	14,090	13,990–14,195	ULN-15D0065	1
38	Tower 9 Borrow Pit	670.7	bulk organic carbon	100	110	9400 ± 50	n/r ^b	10,630	10,505–10,745	ULN-15D0006	1
59	Core MD-1	651.0	<i>Anodonta</i> sp. (n = 1)	745	745	28,670 ± 4500	-4 ^c	32,670	30,960–34,535	A-451	14
<i>Salt Wells Valley</i>											
54	Salt Wells Valley	640.9	<i>Anodonta</i> sp. (n = 1)	0	0	12,030 ± 100	n/r	13,890	13,700–14,135	Beta-211,387	12
54	Salt Wells Valley	640.9	<i>Anodonta</i> sp. (n = 1)	0	0	12,440 ± 70	n/r	14,565	14,190–14,985	Beta-211,388	12
54	Salt Wells Valley	640.9	<i>Anodonta</i> sp. (n = 1)	0	0	12,450 ± 90	n/r	14,595	14,180–15,045	Beta-211,384	12
54	Salt Wells Valley	640.9	<i>Anodonta</i> sp. (n = 1)	0	0	12,480 ± 60	n/r	14,670	14,265–15,040	Beta-211,385	12
54	Salt Wells Valley	640.9	<i>Anodonta</i> sp. (n = 1)	0	0	13,800 ± 70	n/r	16,695	16,410–16,970	Beta-211,389	12
53	Salt Wells Valley, spillway	634.0	<i>Anodonta</i> sp. (n = 1)	0	0	12,740 ± 260	-4.7	15,090	14,120–15,930	Beta-190,570	13
53	Salt Wells Valley, spillway	634.0	<i>Anodonta</i> sp. (n = 1)	0	0	12,760 ± 170	-5.4	15,175	14,400–15,760	Beta-190,572	13
55	Shell Beach, outlet channel	651.1	<i>Anodonta</i> sp. (n = 1)	0	0	12,150 ± 35	n/r ^b	14,040	13,905–14,170	ULN-15D0096	1
55	Shell Beach, outlet channel	649.9	<i>Helisoma newberryi</i> (n = 1)	0	0	11,550 ± 50	-8.0	13,385	13,285–13,475	Beta-280,686	2
<i>Inflow Drainages</i>											
40	Indian Wells Canyon, 6Ob horizon	991.6	bulk organic carbon	370	375	10,240 ± 50	-24.8	11,970	11,760–12,150	Beta-280,735	2
40	Indian Wells Canyon, 2Ab horizon	988.9	bulk organic carbon	265	275	8790 ± 40	-24.6	9810	9625–9940	Beta-237,061	2
40	Indian Wells Canyon, 3Ab horizon	991.6	bulk organic carbon	300	300	9750 ± 50	-24.5	11,190	11,090–11,250	Beta-272,225	2
41	Indian Wells Valley, Hwy 178	1145.0	bulk organic carbon	130	135	9490 ± 50	n/r ^b	10,760	10,585–10,870	AA-76634	9
42	Little Dixie Wash, Locality 1, 2Ab horizon	830.6	<i>Helisoma newberryi</i> (n = 1)	175	175	10,000 ± 60	-11.6	11,485	11,265–11,725	Beta-272,226	2
42	Little Dixie Wash, Locality 1, 2Ab horizon	830.6	bulk organic carbon	190	205	9610 ± 50	-25.3	10,945	10,765–11,165	Beta-272,227	2
42	Little Dixie Wash, Locality 1, 3Ab horizon	830.6	bulk organic carbon	260	280	10,120 ± 60	-25.6	11,740	11,585–12,005	Beta-272,228	2
43	Little Dixie Wash, Locality 3, 3Ab horizon	836.0	bulk organic carbon	195	210	9440 ± 95	-25.2	10,705	10,480–11,100	OS-79584	2
43	Little Dixie Wash, Locality 3, 4Ab horizon	836.0	bulk organic carbon	260	265	10,000 ± 55	-24.9	11,480	11,265–11,715	OS-79563	2
43	Little Dixie Wash, Locality 3, 5Ab horizon	836.0	bulk organic carbon	295	300	10,100 ± 110	-25.1	11,685	11,270–12,065	OS-79585	2
43	Little Dixie Wash, Locality 3, 6Ab horizon	836.0	bulk organic carbon	310	330	10,100 ± 55	-25.5	11,695	11,400–11,975	OS-79564	2
43	Little Dixie Wash, Locality 3, 7Ab horizon	836.0	bulk organic carbon	340	360	10,500 ± 60	-25.7	12,455	12,365–12,635	OS-79565	2
44	Little Dixie Wash, Locality 4, 3Ab horizon	848.5	bulk organic carbon	150	160	9930 ± 40	-25.2	11,325	11,235–11,410	Beta-280,681	2
44	Little Dixie Wash, Locality 4, 5Ab horizon	848.5	bulk organic carbon	200	220	10,510 ± 50	-25.6	12,475	12,375–12,640	Beta-280,734	2
44	Little Dixie Wash, Locality 4, 7Ab horizon	848.5	bulk organic carbon	265	270	10,450 ± 40	-25.5	12,385	12,135–12,540	Beta-280,682	2
45	Little Dixie Wash, Locality 5, 4Ab horizon	860.6	bulk organic carbon	275	295	6340 ± 40	-23.2	7275	7170–7330	Beta-281,208	2
45	Little Dixie Wash, Locality 5, 3Ab horizon	860.6	bulk organic carbon	220	245	6990 ± 40	-23.2	7825	7720–7885	Beta-281,207	2
46	Caltrans Pit, n. pit, 2Ab horizon, stratum III	1031.2	bulk organic carbon	70	80	985 ± 45	-22.0	885	790–970	OS-79583	2
46	Caltrans Pit, n. pit, 3Cu horizon, stratum II	1031.2	bulk organic carbon	250	260	8790 ± 40	-25.0	9810	9625–9940	Beta-280,684	2
47	Caltrans Pit, s. pit, 3Ab horizon, stratum. III	1031.3	bulk organic carbon	200	220	9980 ± 55	-24.1	11,445	11,250–11,645	OS-79587	2
47	Caltrans Pit, s. pit, 4Ob horizon, stratum II	1031.3	bulk organic carbon	470	470	11,560 ± 50	-25.9	13,395	13,285–13,480	Beta-280,685	2
47	Caltrans Pit, s. pit, black mat	1031.4	bulk organic carbon	200	220	10,000 ± 40	-25.0	11,470	11,275–11,630	W-4519	10
48	Cinder Flat	1012.7	bulk organic carbon	60	80	9180 ± 100	-22.8	10,370	10,185–10,590	Beta-260,151	2

(continued on next page)

Table 1 (continued)

Fig. 2 #	Locality/Context	Sample Elevation (meters amsl)	Material Dated	Depth (cm bs)		¹⁴ C yr BP	¹³ C/ ¹² C (‰)	Calibrated years BP ^a		Lab No.	Ref.
				Min.	Max.			Median Probability	2-sigma range		
49	Dead Chevy Flat, 2Ab horizon	1016.1	bulk organic carbon	80	100	9720 ± 100	−24.1	11,095	10,740–11,290	Beta-260,156	2
50	Fossil Falls, INY-1662, CU N12/W3	1009.5	<i>Planorbella trivolvis</i> (n = 1)	150	160	10,660 ± 50	n/r ^b	12,635	12,555–12,710	ULN-14D0066	1
51	Lava end, 2Ab horizon	1019.0	bulk organic carbon	50	70	4440 ± 80	−23.0	5075	4865–5295	Beta-260,152	2
51	Lava end, 2Ab horizon	1019.0	bulk organic carbon	40	60	6770 ± 100	−22.2	7630	7460–7800	Beta-260,155	2
51	Lava end, black mat	1019.0	bulk organic carbon	160	170	9410 ± 100	−25.5	10,655	10,370–10,890	Beta-260,153	2
51	Lava end, black mat	1019.0	bulk organic carbon	175	185	8120 ± 100	23.1	9065	8700–9320	Beta-260,154	2
52	Rose Valley Flat	1015.2	bulk organic carbon	10	20	7320 ± 80	−23.7	8130	7990–8325	Beta-260,150	2
39	Dove Springs Wash, base of terrace	878.9	charcoal, conifer branch	240	250	10,740 ± 110	−25.0 ^c	12,660	12,415–12,835	Beta-018,449	11
39	Dove Springs Wash, 13Ab horizon stratum I	904.0	bulk organic carbon	430	450	10,300 ± 60	−25.4	12,100	11,925–12,390	OS-79560	2
39	Dove Springs Wash, 5Ab horizon, stratum X	906.8	bulk organic carbon	102	112	4230 ± 40	−23.4	4755	4625–4762	Beta-280,993	2
39	Dove Springs Wash	903.5	Succineidae	133	137	9950 ± 50	−7.9	11,375	11,241–11,510	AA-76626	9
39	Dove Springs Wash	903.5	Succineidae	167	195	10,150 ± 50	−8.1	11,820	11,605–12,050	AA-76625	9
39	Dove Springs Wash, basal deposit	903.5	Succineidae	280	290	10,510 ± 60	−9.6	12,470	12,370–12,645	AA-76628	9

Notes: Fig – Figure; amsl – above mean seal level; cm bs – centimeters below surface; Min. – minimum; Max. – maximum; ref. – reference; n/r – not reported; n/m – not measured. References: (1) this study; (2) Meyer et al., 2011; (3) Davis and Panlaqui 1978; (4) Basgall 2004; (5) Couch 2003; (6) Rosenthal and Ugan 2013a; (7) Rosenthal and Ugan 2013b; (8) Byrd 2007; (9) Pigati et al., 2012; (10) Jayko et al., 2011a; (11) Whistler 1990; (12) Jayko et al., 2011b, Kaldenberg 2006; (13) Hildebrandt and Darcangelo 2006; (14) Smith and Pratt 1957.

^a Calibrated years before present (Libby half-life of 5568 years) with maximum 2-sigma range and median probability of the distribution curve rounded to the nearest 5.

^b ¹³C/¹²C ratios were measured in the AMS unit accounting for environmental and machine fractionation; they are unique to each sample and not reported.

^c Estimated delta 13 based on similar material. For *Anodonta* sp. we use $-4 \pm 2\%$ following Reheis et al. (2015). For wood charcoal and bulk organic carbon we use $-25 \pm 2\%$ following Stuiver and Reimer 1993.

Accelerator Mass Spectrometry Facility (NOSAMS) at the Woods Hole Oceanographic Institution, and Eckert-Ziegler Vitalea Arch-lab (Vitalea). Similar methods were employed at all three labs. Bulk organic carbon was treated with acid washes, while shell and tufa was acid etched prior to graphitization. The resulting ages were corrected for natural isotopic fractionation by split sample measurement on a mass spectrometer (BETA, NOSAMS) or direct measurement in the BioMICADAS AMS unit (Vitalea) to account for both natural and machine fractionation.

All radiocarbon dates discussed here have been calibrated to years before present (cal BP) using CALIB version 7.1 and the IntCal13.14c dataset (Reimer et al., 2013; Stuiver and Reimer, 1993). Individual dates are identified in Table 1 by their original lab number and reported as the calculated median probability with a 2-sigma (95%) confidence interval. Due to potential contamination from ambient ¹⁴C-depleted carbon in groundwater and lacustrine systems, radiometric analysis of shell and tufa can result in age estimates that are older than the true age of the sample – the hard water effect (e.g., Benson, 1993; Bischoff et al., 1993; Brennan and Quade, 1997; Pigati et al., 2004, 2010). Radiometric dates on tufa can also be contaminated by exposure to meteoric water after formation, resulting in age estimates that are too young. For tufa dates obtained during this study, we carefully selected samples from the dense interior of the formation to minimize meteoric contamination.

In groundwater systems, ¹⁴C-depleted carbon derives from two main sources: 1) dissolution of carbonate bedrock or other carbon-bearing geological deposits; and 2) radioactive decay as water travels through the aquifer (e.g., Brennan and Quade, 1997; Pigati, 2002; Pigati et al., 2004, 2010). Incorporation of old carbon from these sources during shell formation can result in radiometric ages from mollusk shells that are hundreds to thousands of years too old (e.g., Brennan and Quade, 1997; Pigati et al., 2004, 2010). Since bedrock in the watershed of Indian Wells Valley is primarily granite

and basalt, re-dissolved ¹⁴C-depleted carbon from this geologic source should be negligible in local mollusk shells (Brennan and Quade, 1997; Claassen, 1985). However, groundwater travel times during the late Pleistocene and early Holocene are unknown for Indian Wells Valley and may influence the apparent age of radiocarbon-dated mollusks, particularly those that lived near spring orifices where the ¹⁴C content of host-waters should be lowest (Brennan and Quade, 1997).

Aquatic and semi-aquatic mollusks that lived in local streams and rivers removed from emergent groundwater, such as the Owens River and Little Dixie Wash, may require little or no reservoir correction since surface waters are commonly at or near equilibrium with ¹⁴C in the atmosphere (Brennan and Quade, 1997; Claassen, 1985; Pigati et al., 2004). For the same reason, mollusks living in freshwater lakes fed by surface water may be less affected by ¹⁴C-depleted carbon than those in groundwater-fed springs, although, dissolution of old carbon from the lakebed itself can occur.

Previous work by Brennan and Quade (1997) and Pigati et al. (2004, 2010) has shown that some minute (>10.0 mm) terrestrial and semi-aquatic (pulmonate) gastropods do not require a reservoir correction, as they incorporate little to no ¹⁴C-depleted carbon during shell formation. This is supported by dates on bulk organic carbon (OS-79560), wood charcoal (Beta-018449), and Succineidae shell (AA-76628) from the deepest organic horizon at Dove Springs wash (Table 1). These three dates differ by a maximum of 440 radiocarbon years, with wood charcoal providing the oldest date and bulk organic carbon providing the youngest. Since dates from wood charcoal should not suffer from the hard-water effect, younger ages for the gastropod shell and bulk organic carbon in the same stratum, suggest that these latter samples have incorporated little or no old carbon. Paired dates from bulk organic carbon (Beta-272227) and shell of the pulmonate gastropod, *Helisoma newberryi* (Beta-272226), in the same stratum at Little Dixie Wash (2Ab

horizon of locality 1), provide a similar result, differing by 390 radiocarbon years (Table 1). Although the gastropod shell is older than the organic carbon, both are in stratigraphic order when compared to dates from underlying strata. Furthermore, the ^{14}C age of bulk organic sediment reflects the mean residence time of the total organic content of the analyzed sample (e.g., Scharpenseel, 1979). Since these organic horizons are time transgressive, mean residence dates should be younger than the maximum age of the associated deposit (e.g., Matthews, 1985; Scharpenseel, 1979), consistent with results from Little Dixie Wash and Dove Springs Wash. Although we cannot rule out contamination from ^{14}C -depleted carbon, the paired dates indicate that little or no reservoir correction is necessary for minute, pulmonate gastropods from these local drainages.

The greatest degree of uncertainty lies with the age of mollusks in ground-water fed springs and fully aquatic mollusks (e.g., *Anodonta* sp., *Sphaerium* sp., *Valvata* sp.) and tufa from China Lake basin and Salt Wells Valley. To minimize the hard-water effect in lacustrine and spring samples, where possible, we selected only minute, pulmonate gastropods for dating (no terrestrial Succineidae species were present in our samples). In several other instances, only fully aquatic pelecypod and gastropod shells or tufa were available for analysis. Unfortunately, no reservoir correction has previously been calculated for these types of samples in either China Lake basin or the upstream basin of Owens Lake (e.g., Bacon et al., 2006; Benson et al., 1996, 1997; Reheis et al., 2014; Smith and Bischoff, 1997), and appropriate samples to make this correction were not identified during our study. In Searles basin, Lin et al. (1998) calculated a reservoir correction for tufa of approximately 330 years. Proposed corrections for aquatic fauna from lakes in the Mojave River system range between 90 and 350 years (e.g., Berger and Meek, 1992; Miller et al., 2010; see also Culleton, 2006), although Miller et al. (2010) conclude that a correction of 140 years best fits the few available late Holocene radiocarbon pairs (see also Reheis et al., 2015). In Las Vegas Valley, Springer et al. (2015:Table S3) show that the pulmonate gastropod *Physa* sp. requires just 50% of the hard water correction applied to fully aquatic species.

At this point, we have no way of judging the extent to which ^{14}C -depleted carbon is influencing the apparent age of mollusks and tufa from China Lake basin and Salt Wells Valley. Since, for the same reason, existing lake-level curves for Owens Lake (e.g., Bacon et al., 2006; Reheis et al., 2014), Searles Lake (Smith, 2009) and Panamint Lake (Jayko et al., 2008) did not incorporate a reservoir correction, we omit that adjustment here for comparative purposes. As a consequence, ^{14}C determinations from tufa and aquatic and semi-aquatic mollusks reported in Table 1 are considered maximum ages and may be as much as 140–350 years older than the true age of the sample. We apply reservoir corrections to mollusk and tufa dates from China Lake basin and Salt Wells Valley in Supplement 4, and construct a corrected lake level curve for comparison with other regional records.

² Mollusks, ostracodes and calcareous algae were identified by M. Palacios-Fest using Terra Nostra Earth Sciences Research, LLC internal reference collection and standard literature references. For mollusks, these included Clarke (1981), Dillon (2000), Frest and Johannes (1999); and Rutherford (2000). References for ostracode identification included Delorme (1970a, 1970b, 1970c, 1970d, 1971) and Forester et al. (2005). Calcareous algae were identified based on Wood (1967). Fishes were identified by K. Gobalet using comparative collections housed at the Department of Biology at California State University, Bakersfield and the California Academy of Sciences, San Francisco. Paleobiological collections reported as part of this study are curated at the Naval Air Weapons Station China Lake Museum.

2.2. Paleobiota

A total of 71 samples from 31 localities in China Lake basin ($n = 25$), Dove Springs Wash ($n = 1$), Little Dixie Wash ($n = 2$), Rose Valley ($n = 2$), and Salt Wells Valley ($n = 1$) was analyzed for pelecypods, gastropods, ostracodes, calcareous algae, and/or other aquatic and semi-aquatic faunas² (Tables 2 and 3). At some localities, only selected mollusks were collected for purposes of radiocarbon dating, while at other locations entire sediment samples were analyzed for the full-range of paleobiological and sedimentological information.

Because a great majority of the identified invertebrates are generalists and can live in a wide range of perennial water habitats, including lakes, springs, ponds, and streams, we focus on species that provide the clearest evidence for paleohydrological and other environmental conditions. Among pelecypods, the best indicator for lacustrine habitats in China Lake basin is *Anodonta* sp. cf. *Anodonta californiensis*. This species requires a viable fish population to disperse and complete its lifecycle, while glochidia and juveniles are sensitive to acidic and oxygen-deprived conditions (Smith, 2001:371–377). As a result, the presence of this species reflects sustained surface and/or groundwater input sufficient to maintain suitable water chemistry for both *Anodonta* sp. and fish populations. *Anodonta* sp. are most common in waters less than 2 m deep, but regularly occur as deep as 7 m in large lakes (Smith, 2001:375). In China Lake basin, this species also indicates persistent freshwater conditions since the last connection to source populations in the upper Owens River system.

Gastropods recovered from China Lake basin and its feeder drainages are all aquatic (gill breathers) or semi-aquatic (pulmonate) species that occupy a wide range of permanent water habitats from lakes to springs to streams in fresh to Ca- or HCO_3 -rich waters (Table 2). Like the pelecypods, most of the identified gastropods occupy waters from 10 cm to 2 m deep. One exception in the current assemblage is *Vorticifex effusa* which lives in cold deep water (Duncan, 2008). Some species, such as *Planorbella trivolvus*, are typically associated with well-vegetated, eutrophic environments (Bequaert and Miller, 1973), while others including *Valvata humeralis*, *Aplexa hypnorum*, and *Physa ancillaria* are typical of cold, fresh- to HCO_3 -rich water with low salinity (Sharpe, 2002).

All 14 samples analyzed for ostracodes contained these microcrustaceans (Table 3). Ostracodes identified from China Lake basin and its feeder drainages, like the gastropods, include numerous forms adapted to a broad range of environments where eurytopic species such as *Cypridopsis vidua* and *Condana patzcuaro* co-occur with stenotopic species including *Pelocypris alata-bulbosa*, *Prionocypris canadensis*, and *Fabaeformiscandona acuminata*. The latter three are cryophilic species restricted to low temperature and low salinity, but alkaline-rich environments. *Limnocythere ceriotuberosa* is one of the most abundant and ubiquitous ostracode species identified from China Lake basin and is common in other pluvial lake systems in the Mojave Desert (e.g., Bright and Anderson, 2005; Forester et al., 2005; Garcia et al., 2014; Lowenstein et al., 1999; Wells et al., 2003). This species is also abundant in the fossil record of Owens Lake and is typically associated with lacustrine settings that have a large seasonal fluctuation in size and hydrochemistry due to changes in surface water and/or groundwater input (Bradbury and Forester, 2002; Forester et al., 2005). Another important species is the salt-tolerant *Limnocythere sappaensis* which has been identified in lacustrine deposits from throughout the Mojave Desert, including Panamint Valley (Jayko et al., 2008) and Death Valley (Forester et al., 2005). It is more salt tolerant than *L. ceriotuberosa* and, like the latter species, represents periods when an alkaline-saline

Table 2
Identified gastropod and pelecypod species by elevation.

Fig. 2 #	Sample	Depth (cm bs)	Total (ct.)	Stagnicola sp. cf. S. palustris	Stagnicola elodes	Physella virgata	Physa sp. cf. P. ancillaria	Physa sp. cf. P. bulla	Physella gyrina aurea	Aplexa sp.?	Aplexa sp. cf. A. elata	Pseudosuccinea columella	Fossaria parva	Lymnaea stagnalis
				ct.	ct.	ct.	ct.	ct.	ct.	ct.	ct.	ct.	ct.	ct.
55	Shell Beach, Salt Wells Valley	Surface	3	–	–	–	–	–	–	–	–	–	–	–
25	Lower Playa Cut	0–20	312	4	–	–	–	–	48	6	–	–	3	–
32	SBR-12391, Gully	10–20	129	–	–	–	–	–	–	–	–	–	–	–
10	Dike Lake, Stratum III	105–135	61	–	–	–	–	–	–	–	–	–	–	1
10	Dike Lake, Lower Shell Bed, Strat IV	100–105	250	–	1	–	–	–	–	–	–	–	–	–
10	Dike Lake, Upper Shell Bed, Strat VI	85–90	507	–	–	–	–	–	–	–	–	–	–	2
31	SBR-12390	0–10	1	–	–	–	–	–	–	–	–	–	–	–
32	SBR-12391	0–10	66	–	–	–	–	–	–	–	–	–	–	–
11	Dune Quarry	n/a	7	–	–	–	–	–	–	–	–	–	–	–
17	KER-5598	10–07	27	–	–	–	–	–	–	–	–	–	–	–
13	GZAP Borrow Pit	25–35	40	2	–	–	–	–	–	–	–	–	–	–
27	Mussel Playa West	0–10	49	–	–	1	–	–	–	–	–	–	–	–
28	Mystery Site	0–10	1+	–	–	–	–	–	–	–	–	–	–	–
14	Homestead Pit	120–130	1150	–	–	2	–	–	–	–	–	–	13	–
23	Knox Road Cut	90	177	–	–	–	–	–	–	–	–	–	–	–
36	Tower 7 Borrow	36	86	–	–	2	–	–	–	–	–	–	8	–
7	Charlie Tower Pit 2	50	154	–	–	2	–	–	14	–	–	–	3	3
7	Charlie Tower Pit 1	120	89	–	–	1	–	–	2	–	–	–	–	–
16	Huge Pit	430	287	–	–	1	–	–	–	–	–	–	33	–
18	KER-5611 (10 samples)	0–90	25	–	–	–	–	–	–	–	–	–	–	–
21	KER-6966	70–80	4	–	–	2	–	–	–	–	–	–	–	–
22	KER-6968, (4 samples)	10–80	5	–	–	1	–	–	–	–	–	–	–	–
6	Basalt Ridge, INY-5825	0–10	1+	–	–	–	–	–	–	–	–	–	–	–
34, 35	TO-39, Localities 1–7 (7 samples)	Surface	45	17	7	1	–	–	–	–	–	–	–	–
3	Baker Borrow Pit 2	130	19	–	–	–	–	–	10	–	–	–	–	–
3	Baker Borrow Pit, Locality 1	175–185	461	55	22	80	1	1	–	–	29	–	–	–
3	Baker Borrow Pit, Locality 3	80–100	1174	160	79	286	–	–	–	–	85	–	–	–
2	Alrite Pit	150	32	–	–	11	–	–	–	–	–	–	–	–
–	KER-5910	surface	1	–	–	–	–	–	–	–	–	–	–	–
4	Baker Camera Pit	210	15	–	–	–	–	–	2	–	–	–	–	–
42	Little Dixie Wash, Locality 1, 2Ab horizon	190–205	34	–	–	–	–	–	–	–	–	–	–	–
43	Little Dixie Wash, Locality 3, 4Ab horizon	260–265	12	–	–	–	–	–	–	–	–	1	4	–
43	Little Dixie Wash, Locality 3, 3Ab horizon	195–210	5	–	–	–	–	–	–	–	–	–	5	–
39	Dove Springs Wash-8Ab	220–225	42	–	–	1	–	–	–	–	–	–	–	–
50	Fossil Falls, CA-INY-1662 (2 samples)	50–150	10	–	2	–	–	–	2	–	–	–	–	–
46	Caltrans Pit, north, 3Cu horizon	250–260	2	–	–	–	–	–	–	–	–	–	–	–

Notes: cm bs – centimeters below surface; ct. – count; cal BP – median probability of calibrated intercept of radiocarbon date; amsl – above mean sea level; + - present.

lake was supported by seasonal stream flow (Forester et al., 2005). In Panamint Valley, the presence of *L. ceriotuberosa* and *L. sappaensis* was used as a proxy for inflow from the lower Owens River (Jayko et al., 2008). As these species cannot survive in calcium- and alkaline-enriched water typical of local groundwater and spring sources (Bright and Anderson, 2005; Forester et al., 2005; Güler and Thyne, 2006), we use them to infer the presence of a seasonally fluctuating lake.

3. Lacustrine, spring, and groundwater deposits from China Lake basin and upper Salt Wells Valley

The near-surface stratigraphic record from China Lake basin and upper Salt Wells Valley provides comparatively detailed paleohydrological evidence spanning the period between >32,000 and

9500 cal BP. Most of the 36 sample localities are surface deposits or near-surface sections (<1.5 m below surface), ranging in altitude between 658 and 681 m amsl (Fig. 2). Near the Owens River distributary system, on the western edge of the basin, discrete strata of fine sand, silt, and clay are characteristic of lacustrine, spring, and other wetland habitats often interbedded and capped by coarse alluvial fan and aeolian deposits. Near the valley depocenter, at the eastern end of the basin, deposits of fine sand, silt, and clay form expansive stratified playas that developed under lacustrine conditions and have subsequently been modified by aeolian and fluvial processes. Mechanical and natural exposures from throughout the basin often contained diverse aquatic and semi-aquatic molluscan faunas, ostracodes, and more rarely the bones of mammals, fishes, amphibians, and birds.

Lymnaea sp.	Planorbella trivolvis	Helisoma sp.?	Helisoma (Carinifex) newberryi	Gyraulus parvus	Vorticifex effusa	Valvata sp.	Valvata humeralis	Valvata sp. cf. V. sincera	Valvata tricarinata	Tryonia sp.	Pisidium compressum	Pisidium casertanum	Sphaerium striatinum	Anodonta sp.	Meters (amsl)
ct.	ct.	ct.	ct.	ct.	ct.	ct.	ct.	ct.	ct.	ct.	ct.	ct.	ct.	ct.	
–	–	–	3	–	–	–	–	–	–	–	–	–	–	+	651
–	105	–	–	65	10	–	53	–	–	–	–	–	18	+	659
–	11	5	45	10	6	–	51	–	–	–	–	–	–	+	659
–	13	–	–	20	–	–	25	–	–	–	–	2	–	–	661
–	30	2	5	55	4	–	145	–	–	–	–	9	–	+	661
–	43	7	12	72	47	93	179	–	–	–	6	46	–	+	661
–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	662
–	1	–	–	8	–	–	–	–	56	–	–	–	–	–	662
–	7	–	–	–	–	–	–	–	–	–	–	–	–	–	663
–	–	–	–	2	4	–	–	–	–	–	16	–	5	+	665
–	–	–	–	23	2	–	–	–	–	–	8	–	5	–	665
–	11	3	–	8	–	–	13	–	–	–	–	9	2	+	666
–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	666
29	17	158	132	101	50	–	559	–	–	–	73	–	16	–	669
–	29	2	10	42	–	–	94	–	–	–	–	–	–	–	669
–	3	–	–	108	–	–	–	–	–	–	–	3	–	–	669
–	102	–	–	28	–	–	2	–	–	–	–	–	–	–	669
–	46	–	–	34	–	–	6	–	–	–	–	–	–	–	669
–	3	69	96	21	13	–	6	–	–	35	8	3	–	–	671
–	1	–	–	–	16	–	–	–	–	–	–	–	8	–	672
–	2	–	–	–	–	–	–	–	–	–	–	–	–	–	672
–	–	–	–	–	–	–	–	–	–	–	–	–	4	–	673
–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	675
–	14	–	–	–	4	–	–	–	–	–	–	–	3	–	676
–	5	–	–	4	–	–	–	–	–	–	–	–	–	–	678
–	87	–	–	110	–	–	–	78	–	–	–	–	–	–	681
–	130	–	–	313	–	–	–	121	–	–	–	–	–	–	681
–	8	–	–	13	–	–	–	–	–	–	–	–	–	–	681
–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	681
–	7	–	–	6	–	–	–	–	–	–	–	–	–	–	681
–	–	–	34	–	–	–	–	–	–	–	–	–	–	–	832
–	–	–	3	4	–	–	–	–	–	–	–	–	–	–	832
–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	832
–	–	–	–	–	–	–	–	–	–	4	–	37	–	–	868
–	6	–	–	–	–	–	–	–	–	–	–	–	–	–	1010
–	–	–	–	–	–	–	–	–	–	2	–	–	–	–	1032

3.1. Lacustrine records

Lake features, such as discontinuous beach deposits, beach ridges, wave-cut notches and platforms, and tufa formations, occur at various altitudes in China Lake basin and Salt Wells Valley, offering direct evidence for the elevation of past lake stands (Couch et al., 2004; Davis, 1975; Davis and Panlaqui, 1978; Gale, 1914, 1915; Kunkel and Chase, 1969; Lee, 1913; Moyle, 1963; St.-Amand, 1986). The present altitude of the outflow sill between China Lake basin and Salt Wells Valley is ~665 m amsl according to USGS digital elevation data (U.S. Geological Survey, 2016; see also Smith and Street-Perrott, 1983). Above this elevation, the waters of China Lake and Searles Lake would merge to form pluvial Lake Searles (Smith, 2009; Smith and Street-Perrott, 1983). There is currently no geomorphic expression of the outflow channel at the modern sill location, indicating that recent alluvial and/or aeolian processes

have obscured earlier elevations of the drainage divide. Well logs recorded at the apex of the outflow sill identify bedrock at between 11.2 and 14.3 m below surface (Fig. 2, #58), capped by fine to medium sand (Kunkel and Chase, 1969:31 and Plate 5; Moyle, 1963:236). Based on the surface elevation of the modern sill, bedrock at this location lies at a maximum elevation of approximately 651 m amsl, roughly 1 m below the lowest point on the modern playa. This indicates that past lake impoundments were controlled by a soft sill of alluvium, windblown sand, and/or beach barrier ridges, and the current sill altitude likely represents a maximum elevation for spill-over into Salt Wells Valley and Searles basin.

Geomorphic evidence for the altitude of past lake stands is most apparent on the eastern and northeastern edges of the basin where bedrock ridges and higher-gradient slopes preserve discontinuous shoreline remnants. In this portion of the basin,

Table 3
Identified ostracode species.

Fig. 2#	Sample Locality	Depth (cm bgs)	Bulk wt. (g)	Total (ct.)	Dry-Mass (ct./g)	<i>Limnocythere ceriotuberosa</i> ct.	<i>Limnocythere sappaensis</i> ct.	<i>Limnocythere staplini</i> ct.	<i>Limnocythere paraornata</i> ct.	<i>Limnocythere itasca</i> ct.	<i>Cypridopsis okeechobei</i> ct.
46	North Caltrans Pit, 3Cu horizon	250–260	100.5	28	0.28	–	–	–	–	–	–
39	Dove Springs Wash, 5Ab horizon	102–112	100.7	258	2.56	–	–	–	–	–	–
39	Dove Springs Wash, 8Ab horizon	220–225	100.3	78	0.78	–	–	–	–	–	–
43	Little Dixie Wash, Loc. 3, 4Ab horizon	260–265	100.3	18	0.18	–	–	–	–	–	6
3	Baker Borrow Pit, Loc. 1	175–185	100.1	77	0.77	–	–	–	–	–	–
3	Baker Borrow Pit, Loc. 3	80–100	100.1	358	3.58	–	–	–	–	–	–
2	Alrite Pit	140–150	94.1	11	0.12	–	–	–	–	–	–
13	GZAP Borrow Pit	25–35	100.1	25	0.25	–	–	1	–	–	–
25	Lower Playa Cut	0–20	100.6	335	3.33	45	40	–	17	6	–
36	Tower 7 Borrow Pit	25–35	101.3	64	0.63	26	18	–	–	–	–
10	Dike Lake, Stratum VI	85–90	97.5	104	1.07	8	–	–	–	–	–
4	Baker Camera Pit	200–210	101.9	43	0.42	3	–	–	–	–	–
7	Charlie Tower Pit 1	110–120	101.1	196	1.94	48	5	–	–	–	–
27	Mussel Playa West	0–10	103.2	9	0.09	8	–	–	–	–	–

Notes: cm bgs - centimeters below ground surface; g - grams; ct. - count.

Moyle (1963) identifies a shoreline deposit (Q1s) at ~672–674 m amsl. This deposit lies below a prominent wave-cut notch at an altitude of ~677–678 m amsl and a deposit of rounded pumice gravels and cobbles (Pumice Beach) on a wave-cut platform at ~678 m amsl (Fig. 2, #30; Fig. 3, c). Below the altitude of the outflow sill, a series of recessional shorelines between ~660 and 661 m amsl occur just downslope from a beach ridge reported by Giambastiani and Bullard (2007) at an altitude of 662–665 m amsl (Fig. 3, a). On the southern and western sides of the basin, shoreline features are poorly preserved or obscured by low-gradient alluvial fan deposits and dune formations that developed during the Holocene. However, tufa formations at the base of Pleistocene basalt flows mark a minimum altitude of former lake stands on the northwestern edge of China Lake basin. Tufa outcrops at the Horseshoe locality developed at an altitude of 684–685 m amsl (Fig. 2, #15; Fig. 3, d), while tufa at the Basalt Ridge lies at 677–678 m amsl (Fig. 2, #5&6; Fig. 3, e), similar to the altitude of the Pumice Beach platform and the wave-cut notch to the east. The lowest altitude tufa outcrops sampled during this study occur on a former shoreline at Paxton Ranch (Fig. 2, #29) and near the basin outlet at the Tufa Knoll locality (Fig. 2, #1; Fig. 3, b), situated at altitudes of ~669 and ~665 m amsl, respectively. Likewise, in upper Salt Wells Valley, the apex of a well-preserved beach ridge or tombolo, reaches an altitude of ~678 m amsl (Fig. 2, #56; Fig. 3, f; Meyer et al., 2011), at the same elevation as a distinct strand line of light-colored, fine sand and silt encircling the adjacent bedrock knoll (Fig. 3, f). Down slope on the eastern side of the knoll, a series of more recent recessional shorelines are also apparent between about 660 and 648 m amsl (see Fig. 3, f).

Due to the absence of associated organic material, shoreline features could not be dated directly. Instead, we rely on 55 radiocarbon dates from subaqueous sedimentary deposits, tufas, and mollusks to infer minimum lake altitudes (Fig. 4). Lacustrine contexts were distinguished from spring and stream deposits based on a combination of stratigraphic evidence for the depositional environment, paleobiological content, altitude, and radiometric age. Altitude was determined for each sample by subtracting the depth of the dated deposit from the surface elevation at each locality, as determined by USGS digital elevation data (U.S. Geological Survey, 2016).

3.1.1. >32,000–19,000 cal BP

Limited evidence from China Lake basin provides a discontinuous lacustrine record from >32,000 to ~19,000 cal BP, evincing a shallow lake environment (Fig. 4). At the Homestead Pit and Huge Pit localities (Fig. 2, #14 and #16; Fig. 5, d), lacustrine mollusks, characteristic of cold, slow-moving water (including *Helisoma* sp., *Gyraulus parvus*, *V. humeralis*, *Pisidium compressum*, *Anodonta* sp. and others; Table 2), as well as the bones of indeterminate ray-finned fishes (*Actinopterygii*) and tui chub (*Siphateles bicolor*; Table 4), indicate that a freshwater lake stood above the elevation of the modern outflow sill at an altitude of no less than 668–670 m amsl at least once prior to 32,000 cal BP (Table 1; Fig. 5, d) and China and Searles lakes coalesced (Fig. 4). A similar, but less diverse assemblage of lacustrine mollusks from a stratified beach deposit in the Knox Road Cut indicates that water levels stood above the basin sill, and reached a maximum altitude of 668 m amsl by about 32,500 cal BP, based on a dated *V. humeralis* shell (Table 1, Table 2, Fig. 2, #23). Between 21,940 and 20,345 cal BP (Fig. 4), the lake was at or just above the altitude of its modern outflow sill (665 m) judging by mollusk, ostracode, and calcareous algae from a sandy silt at the GZAP Borrow Pit (665 m amsl) and archaeological site KER-5598 (665.5 m amsl; Fig. 2, #13; Fig. 4). A cold, groundwater-fed lake or marsh is suggested at the GZAP Borrow Pit by the snails *Stagnicola* sp. cf. *S. palustris*, *V. effusa*, *G. parvus*, clams *P. compressum* and *Sphaerium striatinum*, and ostracodes dominated by *Candona patzcuaro* (Tables 2 and 3). The presence of *P. alatabulbosa* (16%) suggests a strong springwater influence, while gyrogonites of *Chara globularis* are consistent with a near-shore, shallow water environment. This is supported by the common occurrence of fine root casts in the sample. A similar assemblage of gastropods and bivalves, with the addition of *Anodonta* sp. fragments at KER-5598, is also characteristic of a perennial, cold-water lake (Fig. 2, #17; Table 2).

The elevation of the lake appears to have fallen at least twice during this interval. At 32,670 cal BP, a shallow lake may have stood at or just above the elevation of the bedrock sill (~561 m amsl), based on a dated *Anodonta* sp. shell from ~7.5 m below surface in core MD-1 (Smith and Pratt, 1957, Table 1; Fig. 2; #59). The shell was recovered from mud containing sedge (38%) and cattail (9%) pollen, as well as pollen from other shallow-water aquatic plants at

<i>Cypridopsis vidua</i>	<i>Candona patzcuaro</i>	<i>Cyprina ophthalmica</i>	<i>Darwinula stevensoni</i>	<i>Prionocypris canadensis</i>	<i>Pelocypris altatubulosa</i>	<i>Potamocypris unicaudata</i>	<i>Physocypris globula</i>	<i>Fabaeformiscandona caudata?</i>	<i>Fabaeformiscandona acuminata</i>	<i>Ilyocypris bradyi</i>	<i>Eucypris meadensis</i>
ct.	ct.	ct.	ct.	ct.	ct.	ct.	ct.	ct.	ct.	ct.	ct.
–	–	–	–	–	–	–	–	–	8	20	–
13	–	–	–	–	–	–	–	–	13	53	179
–	–	–	–	–	–	–	–	–	–	49	29
–	–	–	–	–	–	–	–	–	8	–	4
25	21	–	–	17	–	–	–	–	5	–	9
127	63	51	–	3	–	–	–	–	12	–	101
–	–	–	–	–	6	–	–	–	4	–	1
1	19	–	–	–	4	–	–	–	–	–	–
12	86	–	–	29	7	25	11	–	5	–	26
6	10	–	–	–	–	–	–	–	4	–	–
44	11	–	–	21	–	–	–	–	18	–	–
8	–	–	1	20	3	–	–	–	–	–	5
26	47	–	–	–	–	2	8	–	4	–	6
–	1	–	–	–	–	–	–	–	–	–	–

an altitude of 560.5 m amsl. A dated *Mammuthus* sp. bone from an altitude of 664 m amsl (Davis and Panlaqui, 1978), suggests lake levels were below the modern sill elevation at about 22,480 cal BP (Table 1; Fig. 2, #26). However, very large 2-sigma error ranges for both dates (± 4500 years), make these age estimates unreliable (Table 1).

3.1.2. 19,000–17,000 cal BP

While water levels appear to have remained comparatively low after 19,000 cal BP (Fig. 4), a lake stood above 659 m amsl by 18,760 cal BP judging from a radiocarbon date on a *P. trivolvis* shell collected from the 30-cm-thick marl of Stratum III at the Dike Lake locality (Fig. 2, #10; Fig. 6). A cold, freshwater lake is indicated by the associated gastropods *V. humeralis* and *G. parvus*, and bivalves *Pisidium casertanum* and *Anodonta* sp., while the gastropod *P. trivolvis* reflects a weedy near-shore environment (Table 2). Deep desiccation cracks and fine root holes in Stratum III indicate water levels dropped for an extended period before the near-shore shell-bed of Stratum IV developed around 17,290 cal BP, based on a dated *V. humeralis* shell. Stratum IV at Dike Lake is a coquina-like deposit of high-density gastropod and bivalve shells, including primarily *V. humeralis*, *G. parvus*, *P. trivolvis*, *Helisoma (Carinifex) newberryi*, *V. effusa*, *P. casertanum*, and *Anodonta* sp. (Table 2), as well as the bones of *Catostomus fumeiventris* (Owen's sucker), tui chub, and possible *Rhinichthys osculus* (speckled dace), among other unidentifiable fish bones (Table 4). The stratigraphic and paleontological records are characteristic of a near-shore weedy habitat in a cold, groundwater-fed lake. The lower shell bed at Dike Lake was rapidly buried by a 10-cm-thick stratum of fine silt (Stratum V), probably representing a brief rise in lake elevation and subaqueous, near-shore deposition.

Two other localities situated at ~659 m amsl also record a shallow perennial, groundwater-fed lake at this time (Fig. 4). Stratum II in Core 9 reported by Meyer et al. (2011), is an olive-gray (gleyed) lacustrine deposit of coarse sand that fines upward into very fine sand (Stratum II-11Cg), dated 17,795 cal BP from bulk organic carbon (Fig. 2, #9). Site SBR-12391 (Fig. 2, #33), at roughly the same elevation (~659 m amsl) as the dated stratum in Core 9, produced a near-shore gastropod assemblage including the dominant taxa *Valvata* sp., and *H. newberryi* (Table 2). Also present were

G. parvus, *P. trivolvis*, *V. effusa* and articulated *Anodonta* sp. shells in growth position (Byrd, 2007). Dated shells of *V. humeralis* and *P. trivolvis* provide additional evidence for a weedy, slow-moving, cold-water lake between 17,495 and 17,540 cal BP.

Immediately above Stratum V at Dike Lake, the upper shell bed of Stratum VI developed by 17,075–17,090 cal BP based on dated gastropod shells from that deposit³ (Fig. 6). The medium sand layer of Stratum VI includes a dense accumulation of the same fossil mollusks and fishes as the lower shell bed (Tables 2 and 4), with the addition of *P. compressum*, and the bones of unidentified bird and *anuran*. The ostracode assemblage from Stratum VI is made up of the dominant *C. vidua*, *P. canadensis*, *F. acuminata*, as well as *C. patzcuaro*, and *L. ceriotuberosa* (Table 3). The combined assemblage from Stratum VI is also consistent with a weedy, near shore, cold-water lake with seasonal fluctuations of freshwater. Situated approximately 5-m below the altitude of the outflow sill, the near-shore deposits of Stratum VI indicate that Searles Lake remained separate at this time. In contrast to the stratigraphic record from Dike Lake, a radiocarbon-dated tufa tower at the Horseshoe basalt flow suggests that a coalesced Searles-China Lake formed by 17,155 cal BP and reached a minimum altitude of 684 m amsl (Fig. 2, #15; the highest altitude lake documented by this study). A high lake stand at this time seems contradictory to the internally consistent chronostratigraphic evidence from Dike Lake (Fig. 6). However, substantial overlap at the 2-sigma confidence interval between dates from the Horseshoe Tufa (16,895–17,430 cal BP) and Stratum VI at Dike Lake (16,865–17,265 cal BP), make the precise timing of this transgression difficult to define, falling somewhere between 17,430 and 16,865 cal BP (Table 1). A rise in lake levels to 684 m could only result from Owens River input (e.g., Smith, 2009:81–82; Smith and Street-Perrott, 1983:199), which may also be indicated at the Dike Lake locality by the deposition of more

³ Couch (2003) sent a split sample from this same shell bed to two different radiocarbon laboratories. They returned substantially different dates of $14,060 \pm 50$ ¹⁴C BP and $12,875 \pm 170$ ¹⁴C BP. We sampled a single shell from the same shell bed and received a date $14,050 \pm 30$, almost identical to the first of Couch's dates and in correct stratigraphic position based on three other dates from this section. We conclude that Couch's second date was in error, as suggested by the high standard deviation from that sample.



Fig. 3. Lake shore features and lacustrine tufa formations from China Lake Basin and Salt Wells Valley. (a) shorelines between 665 and 661 m amsl visible above the Playa Cut Locality on the northeastern edge of China Lake basin; Fig. 2, #25. (b) Algal tufa associated with the China Lake outlet at an elevation of 665.5 m amsl; Fig. 2, #1. (c) Water rounded pumice cobbles associated with a wave-cut platform at the Pumice Beach locality, China Lake basin; Fig. 2, #30. (d) Tufa formations at the Horseshoe Basalt locality, China Lake basin; Fig. 2, #15. (e) Tufa formations at the Basalt Ridge locality, China Lake basin; Fig. 2, #15. (f) Beach ridge (tombolo) and visible shorelines in Salt Wells Valley; Fig. 2, #56.

than 75 cm of white lacustrine silt-clay marl (Stratum VII) after ~17,075 cal BP, and the accumulation of close to 1 m of gleyed, fine sand in Core 9 after 17,795 cal BP (Meyer et al., 2011).

3.1.3. 17,000–15,000 cal BP

Following the brief transgression, Searles Lake and China Lake appear to have separated by about 16,695 cal BP (Fig. 4), based on a

dated *Anodonta* sp. shell from the outflow channel in Salt Wells Valley at an altitude of ~641 m amsl (Fig. 2, #54; Jayko et al., 2011b). In China Lake basin at site SBR-12390 (Fig. 2, #31), a dated *Anodonta* sp. shell in growth position from an altitude of 660 m confirms a low-elevation lake occupied the basin until at least 16,200 cal BP (Fig. 5, e). Lake levels increased rapidly after that, reaching an altitude of 668 m amsl by 16,065 cal BP, suggesting Owens River

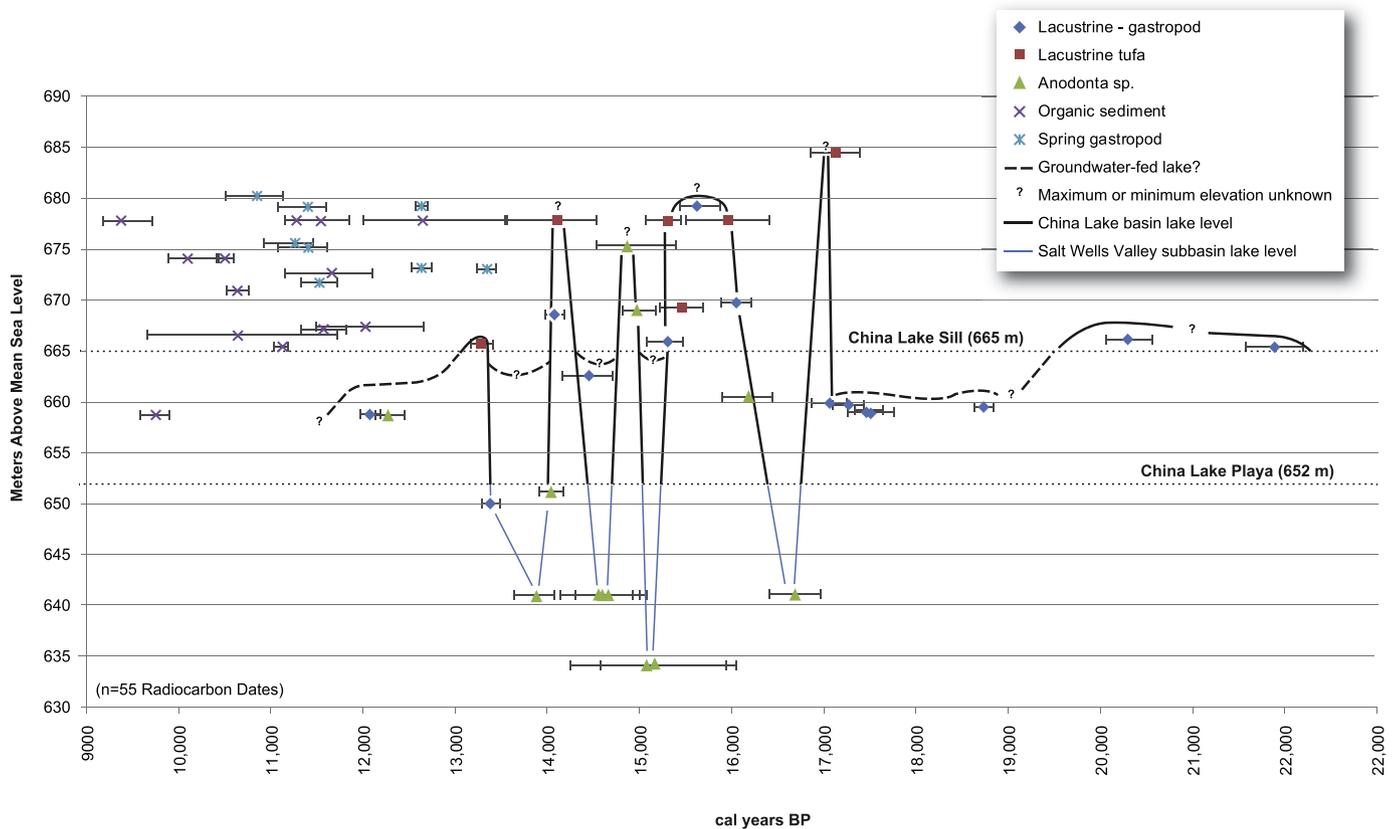


Fig. 4. Comprehensive lake-level curve for China Lake basin and Salt Wells Valley sub-basin between 22,000 and 12,000 cal BP based on 55 radiocarbon dates from mollusks, tufa, and organic sediment recovered at 36 localities.

water once again reached the basin (Fig. 4). China Lake likely coalesced with Searles Lake by this time, judging by a dated *P. trivolvis* shell from an assemblage of lacustrine gastropods and ostracodes in the deeper of two micaceous sandy clay beds at Charlie Tower Pit 1 (669 m amsl; Fig. 2, #7; Table 1). Mollusks from this deposit include the dominant *P. trivolvis* and *G. parvus*, as well as *V. humeralis*, *Physella gyrina aurea*, and *P. virgata* (Table 2). A shallow lacustrine environment is confirmed by an ostracode assemblage dominated by *L. ceriotuberosa*, *C. patzcuaro*, and *C. vidua*, along with *Physocypria globula*, *L. sappansensis*, *Eucypris meadensis*, and *F. acuminata* (Table 3). The calcareous algae *C. globularis* in combination with the dominant gastropod *P. trivolvis* is characteristic of a shallow, weedy lake at this location.

A coalesced lake stood well above the outflow sill at a minimum elevation of 678 m amsl by 15,985 cal BP (Fig. 4), based on dated tufa from the Basalt Ridge locality reported by Davis and Panlaqui (1978; Fig. 2, #5). A sample of this same tufa obtained as part of the current study provided a slightly younger date of 15,315 cal BP. That this high stand may have reached an altitude greater than 695 m amsl is suggested by Jayko et al. (2008) based on a limiting age of 14,925 cal BP for spill-over into Panamint Valley. A minimum altitude for this transgression in China Lake basin is indicated by samples from the Baker Camera Pit at an altitude of ~679 m amsl (Fig. 2, #4). At this locality, the transgression is evident in a 30 cm-thick deposit of micaceous sandy clay resting directly above a loose, poorly sorted and bedded deposit of coarse sand and rounded to subrounded pebbles of a beach or channel deposit associated with the Owens River distributary system. A *P. trivolvis* shell from an assemblage of shallow water gastropods in the clay bed (*P. trivolvis*, *G. parvus*, and *P. gyrina aurea*; Table 2) returned a date of 15,645 cal

BP (Table 1). A cold, lentic habitat with heavy contribution by the Owens River or a nearby spring-source, is indicated by the diverse ostracode fauna including the abundant spring and stream species *P. canadensis* and *P. alatabulbosa* along with the lacustrine *L. ceriotuberosa* and *Darwinula stevensoni* (Table 3). A dominance of the cryophilic species *P. canadensis* (restricted to temperatures <18 °C) and *E. meadensis*, is characteristic of a low-temperature, low-salinity, and alkaline-rich environment (Külköylüoğlu and Vinyard, 2000), implying seasonal or longer-term fluctuations in freshwater input. Common fine root casts in the sediment sample and dominant gastropod *P. trivolvis* are characteristic of a weedy, near-shore setting (<2-m deep). At a lower elevation in the basin, but still well above the outflow sill, the dated Paxton Ranch tufa (669 m amsl) formed ~15,480 cal BP (Fig. 2, #29; Table 1).

Lake levels appear to have dropped to near the altitude of the outflow sill by ~15,320 cal BP (Fig. 4), judging by the paleobiological assemblage from Mussel Playa (665.5 m amsl; Fig. 2, #27). In addition to articulated *Anodonta* sp. shells, the exposed playa produced the clams *P. casertanum*, and *S. striatinum*, along with the dominant gastropods *V. humeralis*, *P. trivolvis*, *G. parvus*, and rare *P. virgata* (Table 2), characteristic of a shallow, weedy, near-shore environment. This interpretation is supported by the high sand content of the playa sediments (>64% medium sand), and sparse ostracode assemblage, including only lacustrine species *L. ceriotuberosa* and *C. patzcuaro* which show evidence of reworking (Table 3). The *Anodonta* sp. date from Mussel Playa is nearly identical to the age of the Basalt Ridge tufa more than 10 m higher in elevation, suggesting that lake levels dropped rapidly by ~15,300 cal BP. While it is possible one of these dates is in error, evidence that China Lake and Searles Lake had separated by

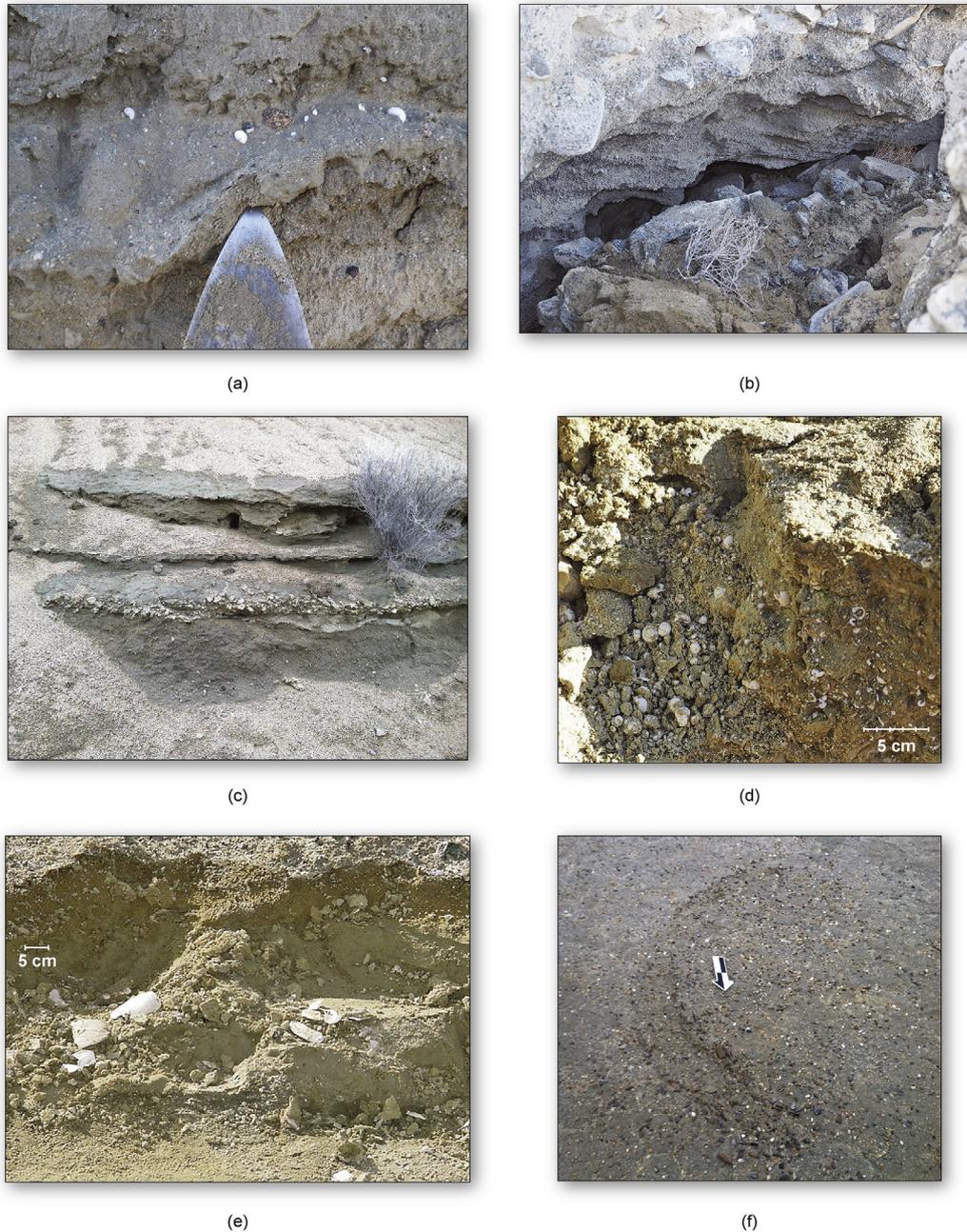


Fig. 5. Spring and lacustrine mollusks and tufa formations and Pleistocene fauna exposed in China Lake basin. (a) Spring-related gastropods exposed in fine sand at the Alrite Pit locality (see Table 2 for list of mollusk species); Fig. 2, #2. (b) Bedded beach deposits of rounded gravels and pebbles exposed below erosional cobble layer at the Dune Quarry locality, China Lake basin. Erosional cobbles are coated in calcium carbonate due to mineral saturation in an evaporating lake; Fig. 2, #11. (c) groundwater-related tufa formed in fine sand and silt at the Alrite Pit; Fig. 2, #2. (d) Dense accumulation of mollusks exposed at the Homestead Pit locality (see Tables 2 and 4 for list of mollusk and fish species); Fig. 2, #15. (e) *Anodonta* sp. shells exposed in the China Lake playa at site SBA-12390; Fig. 2, #31. (f) *Mammuthus* sp. tusk exposed in China Lake playa at 659 m amsl (scale = 20 cm); Fig. 2, #57.

~15,100 cal BP, is provided by *Anodonta* sp. shells from an altitude of 634 m amsl in the outflow channel through Salt Wells Valley, dated 15,175 and 15,095 cal BP (Fig. 2, #53; Hildebrandt and Darcangelo, 2006).

3.1.4. 15,000–13,280 cal BP

Dated *Anodonta* sp. shells from the Mystery Site (669 m amsl) and Basalt Ridge localities (675 m amsl) indicate that China Lake rose rapidly after 15,000 cal BP (Fig. 4), reaching minimum elevations of 669–675 m amsl between 14,980 and 14,880 cal BP, respectively (Table 2; Fig. 2, #6 and #28). Following this

transgression, lake levels declined and China Lake remained at or below its outflow sill (Fig. 4), judging by *Anodonta* sp. shells dated 14,670, 14,595, and 14,565 cal BP from an altitude of ~641 m amsl in Salt Wells Valley (Fig. 2, #54; Jayko et al., 2011b; Kaldenberg, 2006). Rare *P. trivolvis* shells from a thick beach deposit of sorted and bedded, water-rounded pebbles and coarse sand at the Dune Quarry (Table 2; Fig. 5b), indicate China Lake was below the sill at an altitude of about 662 m amsl at 14,455 cal BP (Fig. 2, #11). By 14,120 cal BP, a second tufa date reported by Davis and Panlaqui (1978) from the Basalt Ridge locality indicates a coalesced lake had reformed and reached a minimum altitude of 678 m amsl

Table 4
Identified fish remains from China Lake basin.

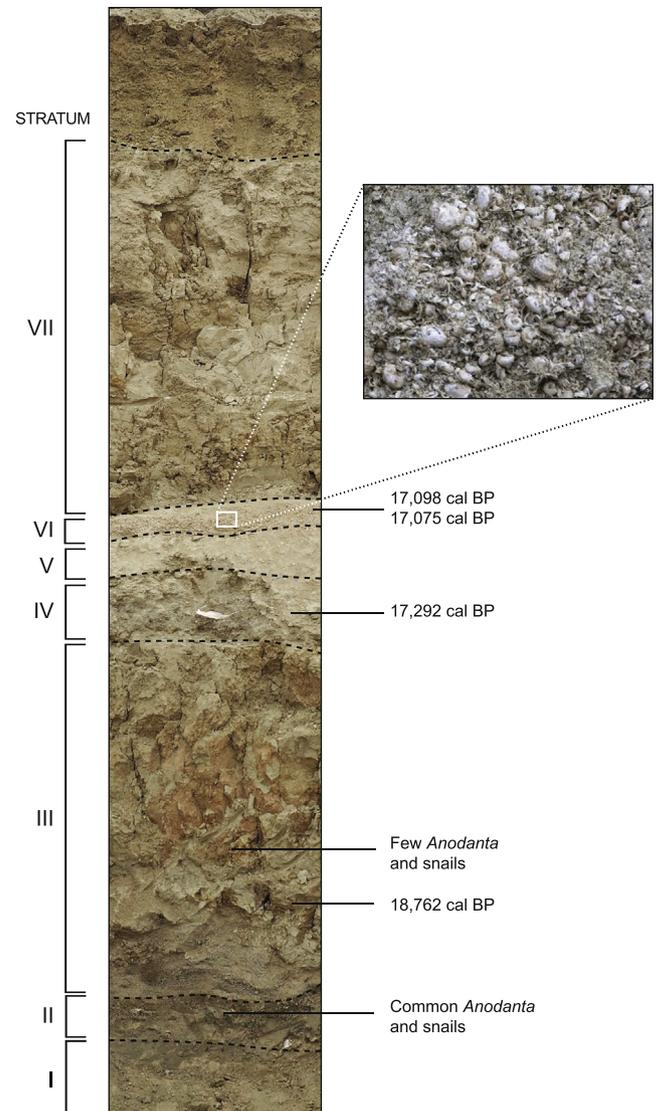
Locality	Taxon	NISP
Homestead Pit	<i>Siphateles bicolor</i>	1
	Actinopterygii	2
Dike Lake, Lower Shell Bed, Strat IV	<i>Catostomus fumeiventris</i>	1
	<i>Siphateles bicolor</i>	2
	<i>Rhinichthys osculus?</i>	1
Dike Lake, Upper Shell Bed, Strat VI	Actinopterygii	15
	<i>Catostomus fumeiventris</i>	91
	<i>Siphateles bicolor</i>	57
	<i>Rhinichthys osculus?</i>	2
	Cyprinidae	43
	Actinopterygii	n/c

Note: NISP – number of identified specimens; n/c - numerous tiny fragments not counted.

(Fig. 4). As a result of rising lake levels, a thick deposit of poorly sorted and faintly bedded, subangular to rounded cobbles and gravels was emplaced over beach deposits at the Dune Quarry (Fig. 5, b). Eroded from the immediately adjacent bedrock slopes, these large clasts are coated with a thick carbonate layer that likely precipitated from mineral-saturated lake water during the subsequent regression.

A coalesced China-Searles lake is further supported by the paleobiological composition of the Tower 7 Borrow Pit at an elevation of 668 m amsl (Fig. 2, #36). The Tower 7 assemblage, dated 14,090 cal BP (*G. parvus* shell), is associated with a deposit of medium sand and is dominated by *G. parvus*, with lesser quantities of *F. parva*, *P. trivolvus*, *P. virgata*, and *P. casertanum* (Table 2). Also present are lacustrine ostracodes, including the dominant *L. ceriotuberosa* and *L. sappaensis* (Table 3). Authigenic carbonate precipitation and encrustation on some ostracode valves and the common salt-tolerant ostracode *L. sappaensis* suggests increasing evaporation and salinization due to calcium carbonate saturation in the system. This is consistent with a declining lake or strong seasonal fluctuations in freshwater. Well preserved shoreline features at an altitude of ~678 m amsl (i.e., wave cut notch and Pumice Beach, Fig. 2, #30) are tentatively correlated with this high stand; there is no evidence for a coalesced lake at or above an altitude of 678 m after ~14,100 cal BP.

Although China and Searles lakes appear to have separated by 14,000 cal BP, water may have continued to spill into Salt Wells Valley. *Anodonta* sp. shells collected from a beach deposit on a wave cut platform (~650 m amsl; Fig. 2, #55; Meyer et al., 2011) and from the outflow channel (~640 m amsl; Jayko et al., 2011b) in Salt Wells Valley (Fig. 2, #54), date to 14,040 and 13,890 cal BP, respectively, providing evidence for a comparatively high, but declining Searles Lake at that time (Fig. 4). However, an *H. newberryi* shell from slightly higher on the same wave cut platform as the oldest *Anodonta* sp., is more than 650 years younger, dating 13,385 cal BP. This later date may indicate a significant carbon reservoir in the *Anodonta* sp. shell. More likely, water levels in Salt Wells Valley dropped between 14,040 and 13,890 cal BP, but rose once again by 13,385 cal BP, fed by spill-over from China Lake basin. This is consistent with a date of 13,285 cal BP from an algal tufa formed at the base of a honey-combed granitic outcrop (Fig. 2, #1; Fig. 3, b) just above the outflow sill in China Lake basin at 665.5 m amsl (Fig. 4; Meyer et al., 2011). This type of tufa forms when lime-secreting algae colonize zones where sunlight regularly penetrates (Scholl, 1960), suggesting the water level was no more than about 2 m above this elevation (Fig. 3, b). China Lake may have continued to receive surface flow from the Owens River, although the lake was confined to an altitude below 673 m amsl, judging by a date of 13,350 cal BP from *S. striatinum* shells at KER-6968 (Fig. 2,



- VII White 2.5Y 9.5/2 silt marl; coarse AB structure; fine horizontal laminations in lower 10 cm; no shell present
- VI Upper shell bed; white 10YR 9.5/1; dense coquina of mollusks and fish bone (close-up); see Tables 2 and 4 for list of species
- V Fine silt, platy structure with mollusks
- IV Lower shell bed, white 10YR 9.5/1; dense coquina of mollusks and fish bone; see Tables 2 and 4 for list of species
- III Silt marl with strong columnar prismatic structure; Bt horizon with distinct thick clay films on ped faces; brown, and few fine root holes
- II 5Y 5/2 olive gray sand
- I Silt 2.5YR 7/1 light reddish gray AB structure; common small root holes with moderate clay films, brown

Fig. 6. Stratigraphic profile of the Dike Lake locality, eastern edge of China Lake basin, with close-up of dense accumulation of mollusks referred to as the upper shell bed, Stratum VI (Fig. 2, #10).

#22). At this site, a single species, *S. striatinum* (Table 2), which prefers lotic habitats (Clarke, 1981), occurred in a silt bed, within a stratified section of fine sand and silty sand, characteristic of a spring-fed stream. Since this locality occurs in a portion of the basin where shallow anastomosed channel segments of the Owens River are still apparent, it may also indicate episodic surface flows through the distributary system.

3.1.5. 13,280–12,000 cal BP

After 13,000 cal BP, the altitude of China Lake remained below the outflow sill and Searles Lake receded from Salt Wells Valley (Fig. 4). The most recent evidence for a sustained lake stand in China Lake basin comes from an altitude of 658.6 m amsl at the Lower Playa Cut locality (Fig. 2, #25). Near-surface sediments (<20 cm below surface) at the Playa Cut are dominated by calcareous fine sandy silt, characteristic of calm water deposition and contain a varied paleobiological assemblage of lacustrine origin. Mollusks from this locality include the bivalves *Anodonta* sp. and *S. striatinum*, as well as the dominant gastropods *P. trivolvis*, *G. parvus*, *V. humeralis*, and *P. gyrina aurea* (Table 2). A diverse lacustrine ostracode assemblage is dominated by *C. patzcuaro*, *L. ceriotuberosa*, and *L. sappansensis*, with lower abundances of several other species (Table 3). This assemblage is characteristic of cold water conditions with seasonal pulses of freshwater, while the common occurrence of fine root casts and calcareous algae *C. canescens* and *C. globularis* suggests shallow water depth. Radiocarbon dates from an *Anodonta* sp. shell and *G. parvus* shell ($n = 25$ individual shells) from the Lower Playa Cut returned similar dates of 12,270 and 12,070 cal BP, respectively. The paleobiological content of the Lower Playa locality indicates that perennial water conditions persisted in the lowest reaches of the basin into the Younger Dryas. Ecological requirements of these species reflect a seasonally fluctuating, alkaline to slightly saline lake, probably no higher than about 661–662 m amsl. This is consistent with the altitude of a series of well-preserved recessional shorelines just upslope from the Lower Playa cut between ~660 and 661 m amsl (Fig. 3, a), and a beach ridge reported by Giambastiani and Bullard (2007) at an altitude of 662–665 m amsl. Dates from the Lower Playa Cut locality suggest these well-preserved shoreline features are Younger Dryas-age (Giambastiani and Bullard, 2007). Higher in the basin at the Basalt Ridge locality, Davis et al. (1981) report a radiocarbon date of 12,655 cal BP from bulk organic carbon in a surface paleosol formed on green and gray lacustrine clay that yielded two partial mammoth skeletons.⁴ Formation of the paleosol is consistent with other evidence that lake levels did not reach an altitude of 677 m amsl after 14,100 cal BP.

3.2. Spring and groundwater-related deposits

As surface flows declined, emergent groundwater continued to influence habitats in China Lake basin. Elevated groundwater levels between 12,700 and 9300 cal BP resulted in the formation of springs or spring-fed stream deposits and organic-rich black mats in the basin at altitudes between 668 and 677 m amsl (Fig. 4). The emergence of groundwater appears to have contributed to the persistence of numerous small spring pools through the Younger Dryas and a small freshwater lake in the lowest reaches of the basin until at least 12,000 cal BP. After ~9300 cal BP, there is no evidence for sustained surface water flow or groundwater-related deposits in China Lake basin.

3.2.1. 12,650–9300 cal BP

On the upper portion of the Owens River distributary fan, mollusks (*P. trivolvis*, *S. striatinum*) from spring-fed stream deposits at archaeological sites KER-6966 and KER-5611 date to 12,635 and 11,525 cal BP, respectively (Fig. 2, #21 and #18; Table 1). Moderately abundant shells of the gastropod *V. effusa* and clam *S. striatinum* from KER-5611 (at an altitude of 673 m amsl; Table 2) are associated with a fining upward sequence of coarse sand grading into fine sand. At KER-6966 (671 m amsl), rare shells of the gastropods *P. virgata* and *P. trivolvis* were identified from a similar buried deposit of fine sand and silt over coarse sand and rounded, pea-sized gravel (Table 2). At a higher altitude (679 m amsl), and further up the Owens River distributary system, the Alrite Pit is also interpreted as a spring-related deposit based on the paleobiological assemblage and stratigraphic sequence composed of fine sand interbedded with coarse sand and small subrounded pebbles (Fig. 5, a). Groundwater precipitated tufa is exposed in an adjacent cutbank of the borrow pit (Fig. 5, c), confirming a nearby spring source. A mollusk assemblage from one of the fine sand beds at the Alrite Pit, dated 12,635 cal BP (*P. trivolvis*; Table 1), includes *G. parvus*, *P. virgata*, and *P. trivolvis* (Table 2). A sparse spring and stream related ostracode assemblage from the same stratum includes only *P. alatabulbosa*, *F. acuminata*, and *E. meadensis* characteristic of cold, dilute water (Table 3). The common gastropod *P. trivolvis* along with the ostracode *F. acuminata* suggests a vegetated spring environment.

Just north of the Alrite Pit, at the same elevation (679 m amsl), the Baker Borrow Pit exposes a deep spring deposit composed of very fine sand, silt, and clay (Fig. 2, #2). Two stratigraphically separate samples produced very similar paleobiological assemblages consistent with a long-lived, well-vegetated spring. A *P. virgata* shell from sandy silt in the bottom of the pit – 175–185 cm below surface – dated 11,400 cal BP, while a *Stagnicola* cf. *S. palustris* shell from just below the coarse alluvium of the modern fan surface (80–100 cm below surface) in a deposit of sandy silty clay, returned a stratigraphically consistent date of 10,840 cal BP. Both contexts include a diverse mollusk assemblage dominated by the gastropods *G. parvus*, *P. virgata*, *Stagnicola* sp. cf. *S. palustris*, *P. trivolvis*, and *Valva* sp. cf. *V. humeralis*, with lower abundances of several other species (Table 2). The ostracode assemblage includes mainly *C. vidua*, *C. patzcuaro*, and *P. canadensis*, as well as *F. acuminata* and *E. meadensis* (Table 3). While most of the ostracode species are eurytopic, three (*P. canadensis*, *E. meadensis*, and *F. acuminata*) are cryophilic and restricted to ecosystems with water temperature below 18 °C and total dissolved solids lower than 1000 mg L⁻¹, consistent with a cold, freshwater spring. To the northeast of the Baker Borrow locality, a similar assemblage of spring-related mollusks occurs at the TO 39 localities (Fig. 2, #34, #35), situated slightly lower in the Owens River distributary system at an altitude of 675 m amsl. Here, several small surface playas expose the gastropods *Stagnicola elodes*, *P. trivolvis*, *P. virgata*, *V. effusa*, and the pelecypod *S. striatinum* (Table 2). Dates of 11,270 and 11,400 cal BP from gastropod shells collected at two of these localities are similar to those from the Baker Borrow pit (Table 1), suggesting widespread groundwater discharge on the western edge of the basin persisted into the early Holocene.

Couch (2003) previously reported a date 11,665 cal BP from bulk organic carbon in a gypsum-rich silt and clay deposit associated with a small hummock on the southeastern edge of the basin (Fig. 2, #24). At an altitude of 672 m amsl, the hummock is part of a broad plume of light-colored silt and clay emanating from the base of a prominent bedrock ridge known as Lone Butte. This sample appears to date a more extensive spring complex that existed in this location during the early Holocene. The modern spring, Lark Seep, is a vestige of this earlier spring complex. On the northern edge of

⁴ Emma Lou Davis obtained a uranium series date for mammoth bone from this stratum of 42,300 ± 3300 BP (Davis et al., 1981).

the basin, at a slightly higher altitude of 677.5 m amsl, Basgall (2005) reports a “spring peat” (bulk organic carbon) and buried soil dating between 11,540 and 11,270 cal BP, respectively, at the Basalt Ridge locality (Fig. 2, #6). Likewise, Davis and Panlaqui (1978) report two dates of 12,025 and 10,635 cal BP on bulk organic carbon in a paleosol from their Stake 1 locality (Fig. 2, #12), more than 11 m lower in the basin, at an altitude of 663 m amsl.

On the western side of the basin on the Owens River distributary fan, thin organic-rich groundwater-related deposits in buried strata of fine sand and silt were identified at two archaeological sites and the Tower 9 Borrow Pit. At KER-6634, a thin, black mat (674 m amsl) was situated just below the surface of a low sand-covered ridge, about 1.2 m above a small playa (Fig. 2, #19). Two samples of bulk organic carbon from the black mat returned dates of 10,085 and 10,495 cal BP (Rosenthal and Ugan, 2013a). The organic horizon appears to represent a wet-meadow that developed alongside a small spring pond. A similar date of 10,630 cal BP was obtained from bulk organic carbon in a dark, groundwater-related horizon that developed in a stratum of medium to fine sand and silt exposed at the Tower 9 Borrow locality (~671 m amsl; Fig. 2, #38). Lower in the basin, at an altitude of 667 m amsl, bulk organic carbon from a thin organic-rich silt deposit at KER-6962 returned an earlier date of 11,565 cal BP (Fig. 2, #20; Rosenthal and Ugan, 2013b). This stratum rested unconformably above light grey-green silt. A similar date of 11,125 cal BP was produced from bulk organic carbon in spring-related, pale-olive, silty clay in Core 9 at 665 m amsl (Meyer et al., 2011).

One of the most recent and lowest altitude groundwater-related deposits identified in China Lake basin is organic sediment collected from the Lower Playa Cut at an altitude of ~659 m amsl. Bulk organic carbon in this near-surface stratum (~5–20 cm below surface) returned a date of 9735 cal BP and originated immediately above white marl. It contained lacustrine mollusks and ostracodes that date at least 2300 years earlier. Differences in these dates suggest that younger organics contaminated older, fossiliferous lake sediments when a spring-fed marsh or other wetland environment developed in the lowest reaches of basin after 12,000 cal BP, following the final decline of China Lake. The near surface context of this sample shows that the modern playa lacks a depositional record after the Late Pleistocene. Widespread Pleistocene-age fossils exposed in the basin below an altitude of 663 m amsl, including the remains of *Mammuthus* sp. (Fig. 5, f), *Equus* sp., *Bison* sp., and *Camelops* sp. (Fortsch, 1978; Springer et al., 2007), agree with the radiocarbon evidence that geological deposits from the early through late Holocene never developed, or have been removed from large portions of the lower basin. Spring discharge appears to have continued well into the early Holocene at the Basalt Ridge locality on the northern edge of the basin (~667.5 m amsl; Fig. 2, #5), where bulk organic carbon from a groundwater-related peat was dated 9360 cal BP (Basgall, 2004). Although this is the youngest groundwater deposit from the basin, it was stratigraphically inverted compared to other dates from this section (Basgall, 2004), and may represent post-depositional disturbance or contamination.

3.3. Synthesis of lacustrine and groundwater deposits from China Lake basin and upper Salt Wells Valley

Radiocarbon, paleobiological, and geomorphic evidence from China Lake basin and the outflow channel through upper Salt Wells Valley provide evidence for five major lake-level transgressions during the terminal Pleistocene, causing China Lake to overtop its sill and spill into Salt Wells Valley. Between 22,000 and 17,200 cal BP, a discontinuous lacustrine record from the basin reflects generally low water levels related to intermittent stream-flow and groundwater and spring discharge. Just before ~17,000 cal BP, the

size of China Lake appears to have expanded substantially due to inflow from the lower Owens River. China and Searles Lakes merged into a single lake, reaching an altitude of no less than 685 m amsl. By 16,700 cal BP, Owens River input ceased, water levels declined, and China and Searles lakes separated. Another rapid rise in lake levels by 16,000 cal BP caused the two lakes to unite and reach a minimum elevation of 678 m amsl. A coalesced Lake Searles may have persisted in both basins up to ~15,300 cal BP. No evidence for a substantial lake is present in China Lake basin between 15,300 and 15,000 cal BP, although a lake was present below an altitude of 640 m amsl in Salt Wells Valley during this span. Between 15,000 and 14,000 cal BP, China and Searles lakes coalesced twice, reaching minimum altitudes of between 675 and 678 m amsl at 14,880 and 14,120 cal BP, respectively. Both of these high-stands were followed by rapid declines in water level and lake separation. China Lake reached its sill elevation of 665 m amsl once more by 13,200 cal BP, but the two lake basins do not appear to have merged. As recently as ~12,100 cal BP, a low elevation, spring-fed lake was present in China Lake basin, but probably did not exceed an altitude of 661–662 m amsl. Between ~12,600 and 11,200 cal BP, elevations below 680 m amsl in China Lake basin contained numerous spring pools, seeps, and related wetland habitats fed by an elevated groundwater table. Organic-rich horizons from throughout the basin suggest that high groundwater levels and mesic habitats persisted until at least 9700 to 9300 cal BP, with all but two localities dating earlier than 10,000 cal BP.

4. Surface and groundwater records from inflow drainages

Rose Valley is the main conduit for surface water flow between Owens and China lakes, so its geomorphic record is critical for understanding the fluvial history of these interconnected basins. Seven locations along the former course of the lower Owens River in Rose Valley provide stratigraphic sections dating between 13,395 and 7800 cal BP. These include the north and south Caltrans pits, Dead Chevy Flat, Cinder Flat, Rose Valley Flat, Lava End, and Fossil Falls (see Fig. 2, #46–52). At each of these localities, stratigraphic sections are exposed in the relatively flat valley axis mapped by Jayko (2009) as Holocene- to Pleistocene-age.

Stream channels exiting the Argus Range and El Paso Mountains in Indian Wells Valley were found to lack stratigraphic exposures from the terminal Pleistocene and early Holocene. However, small, inset terraces dating between about 12,600 and 7200 cal BP were identified at nine locations along three separate Sierra Nevada drainages: Indian Wells Canyon (one locality); Little Dixie Wash (seven localities); and Dove Springs Wash (one locality). Although, Dove Springs Wash drains southward into Koehn Lake basin, its head waters are adjacent to the drainage network that feeds Little Dixie Wash, and the preserved stratigraphic record for the terminal Pleistocene and early Holocene is similar.

All of these localities expose stratified alluvial deposits ranging from coarse fluvial gravels and cobbles to fine-grained sand, silt and clay. Organic-rich horizons (i.e., black mats) in these exposures represent wetland deposits and other groundwater-related habitats often containing aquatic and semi-aquatic mollusks and ostracodes.

4.1. 13,400–12,600 cal BP

Stratigraphic records preserved along the lower Owens River channel, Little Dixie Wash, and Dove Springs Wash provide evidence for the last major period of sustained surface water flow during the terminal Pleistocene, prior to ~13,395 cal BP. Fluvial deposits exposed in the south Caltrans borrow pit in Rose Valley exhibit a basal stratum (Stratum I-5Cu) of coarse sand that grades

downward into a clast-supported layer of rounded to subrounded gravel and cobbles (Fig. 2, #47). These deposits are sorted and bedded, interpreted as the active channel of the lower Owens River (Fig. 7). This fluvial deposit is overlain by a very thin, dark, organic-rich silt (Stratum II-4Ob, or black mat 1), marking a transition from high-energy to low-energy depositional conditions. A radiocarbon date from the 4Ob horizon indicates the organic silt was deposited

about 13,395 cal BP, providing a minimum limiting age for high-energy surface flow in that section of the channel (Jayko et al., 2011a; Meyer et al., 2011).

Just above Fossil Falls, south of the Caltrans Pit, an archaeological excavation conducted within the paleo-Owens River channel recovered an assemblage of semi-aquatic, wetland gastropod shells (*S. elodes*, *P. gyrina aurea*, *P. trivolvris*; Table 2) in

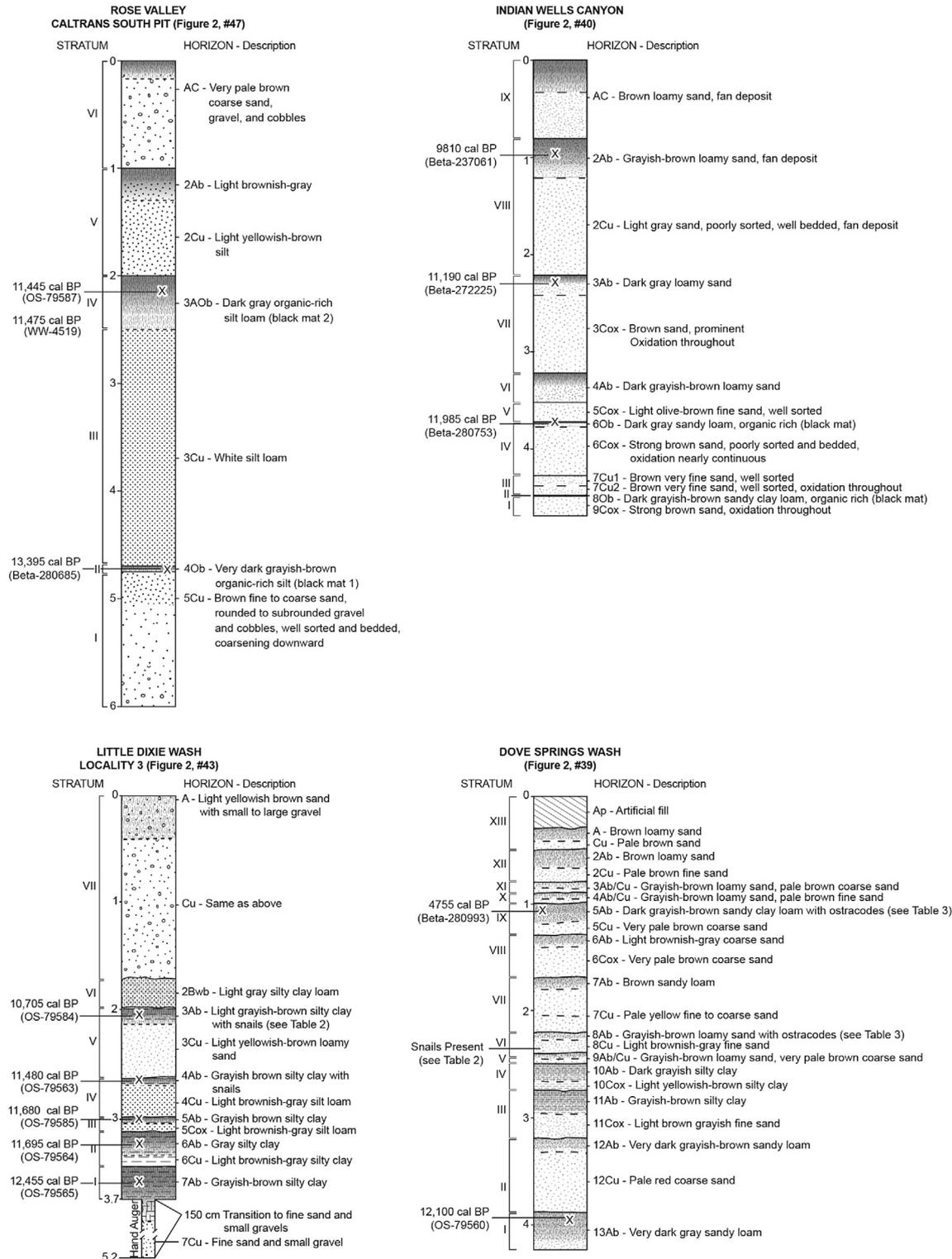


Fig. 7. Late Pleistocene and early Holocene stratigraphic sections exposed in Sierra Nevada drainages at Rose Valley, Indian Wells Canyon, Little Dixie Wash, and Dove Springs Wash.

fine sand and silt beneath a cultural midden (Fig. 2, #50; Gilreath, 1992). Immediately below the fossiliferous stratum was a deposit of pea-gravel and larger water-rounded clasts up to 2 cm in diameter. As part of the current study, a radiocarbon date of 12,635 cal BP was obtained from a *P. trivolvis* shell collected during the archaeological work. This date provides a minimum age for the underlying fluvial deposits in that section of the channel.

All terminal Pleistocene/early Holocene alluvial deposits in drainages emanating directly from the eastern Sierra Nevada are discontinuous terraces set within older Pleistocene-age fans. Basal deposits from Little Dixie Wash and Dove Springs Wash consistently date between about 12,600 and 12,400 cal BP, post-dating the interval of high-energy bed-load and channel activity in Rose Valley. Although fluvial deposits older than 12,600 cal BP were not exposed in these washes, a series of low-energy channel fills and organic-rich black-mats began to form about that time. The broad, incised channels and absence of earlier terrace deposits in these drainages indicate that high energy water flows, channel incision, and lateral migration persisted no later than the early portion of the Younger Dryas (ca. 12,800 cal BP).

4.2. 12,600–11,800 cal BP

Just prior to 12,600 cal BP, roughly synchronous episodes of low-energy deposition and periods of black mat formation are recorded in the fluvial records of Rose Valley, Little Dixie Wash, Dove Springs Wash, and Indian Wells Canyon, marking a decline in stream competency, a shift from high-energy to low-energy depositional conditions, and the emergence of wetland environments within these incised stream channels. The timing of this transition is similar in all of the studied drainages.

At Fossil Falls in Rose Valley (Fig. 2, #50), a 70-cm thick stratum of fine sand and silt was deposited over water-rounded gravels in the lower Owens River channel. This stratum contained an assemblage of air-breathing, semi-aquatic gastropods, including *S. elodes*, *P. trivolvis*, and *P. gyrina aurea* (Table 2). A radiocarbon date of 12,635 cal BP from a *P. trivolvis* shell, suggests a ground-water fed wetland had developed in the channel by that time. In Little Dixie Wash, a basal stratum (Stratum I) of sand and small gravel (7Cu Horizon) fines-upward to a thick black mat formed in silty clay (7Ab Horizon) at Locality 3 (Fig. 7). Bulk organic carbon from the black mat dated 12,455 cal BP. Samples from the deepest organic mats (5Ab and 7Ab horizons) at Locality 4 in Little Dixie Wash returned dates of 12,475 and 12,385 cal BP, respectively (Fig. 2, #44). Although stratigraphically reversed, the dates from Locality 4 overlap substantially at the 2-sigma confidence interval (12,375–12,610 vs. 12,200–12,550 cal BP; Table 2), likely representing successive episodes of deposition and mat formation over a short time span.

At Dove Springs Wash (Fig. 2, #39), bulk organic carbon from the deepest of a series of organic mats (13Ab Horizon) exposed in a cutbank along the first inset terrace, returned a date of 12,100 cal BP (Fig. 7). Whistler (1990, 1994) reported a slightly earlier date of 12,640 cal BP from a conifer branch collected at the base of the same cutbank. Likewise, Pigati et al. (2012) report a date of 12,470 cal BP from a gastropod shell (family Succineidae) also collected in the basal mat exposed along the same section of wash. In Indian Wells Canyon (Fig. 2, #40), a series of alluvial deposits began to accumulate prior to 11,985 cal BP based on a radiocarbon date from bulk organic carbon in a thin black mat near the base of the profile (Stratum IV, 6Ob horizon). A deeper organic mat is also present at the site, but was not dated (Fig. 7).

4.3. 11,800–10,300 cal BP

During this interval, alluvial records from the lower Owens River channel and eastern Sierra drainages consistently record episodic in-filling with fine sand, silt, and clay resulting in the development of inset terraces in medial channel positions. Low-lying channels became groundwater sinks, promoting the development of wetland habitats as indicated by the presence of organic-rich soils and black mats that hosted diverse aquatic and semi-aquatic mollusks and ostracodes. Oxidized horizons, desiccation cracks, and blocky soil-structure reflect intervening periods of lowered groundwater and episodic drying.

In Rose Valley, the south Caltrans pit records the accumulation of as much as 2.5–3.0 m of white, sandy-silt (Stratum III-3Cu) with a very dark, organic-rich horizon in the upper 0.3–0.5 m (Stratum IV-3AOB, or black mat 2; Fig. 7). An assemblage of wetland mollusk shells including, *Helisoma* cf. *ammon*, *Succinea* cf. *rusticana*, *Fossaria* cf. *modicella*, *Gyraulus* cf. *circumstriatus?* or *parvus*, *Lymnaea* cf. *stagnicola*, *V. effusa*, and *Pisidium*, sp., was identified immediately below the black mat of Stratum IV (Jayko et al., 2011a). The uniform, fine-grained texture and presence of air-breathing and gill-breathing gastropods indicate this stratum was deposited in a shallow pond or perennial wetland (Jayko et al., 2011a). Bulk organic carbon from the 3OAb horizon of Stratum III was dated to 11,475 cal BP (Jayko et al., 2011a). A very similar date of 11,445 cal BP was obtained from a second sample of bulk organic carbon for the current study.

Shallow exposures in surface playas at two other locations in Rose Valley between Fossil Falls and the Caltrans borrow pits also record low-energy deposition and formation of organic mats between 11,100 and 10,300 cal BP. At Dead Chevy Flat (Fig. 2, #49), bulk organic carbon from a buried soil (2Ab) that formed on a fan deposit of coarse sand and gravel (Stratum I-2Cox) provided a date of 11,095 cal BP. A discrete layer of coarse and fine sand (Stratum I-6Cu and Stratum II-5Ab) at the Lava End locality (Fig. 2, #51), is capped by an organic-rich black mat formed in silty-clay (Stratum III-3AOB1), dated 10,655 cal BP (bulk organic carbon). At nearby Cinder Flat, a surface playa of fine sand and silt overlies a thin, organic-rich buried soil (2Ab Horizons) also formed in silty-clay (Fig. 2, #48). Bulk organic carbon from the buried soil dated to 10,370 cal BP, similar to the 3Ob1 horizons at the Lava end locality.

Punctuated deposition in Indian Wells Canyon occurred until about 11,190 cal BP based on a radiocarbon date from bulk organic carbon in an organic-rich buried soil (Stratum VII, 3Ab horizon) formed on a deposit of oxidized sand (Fig. 7). Downslope from Indian Wells Canyon along Hwy 178 (Fig. 2, #41), Pigati et al. (2012) report a 3 m-thick section of paleo-spring deposits distinguished by a well-developed black mat dated to 10,760 cal BP, consistent with a relatively high groundwater table at that time.

At Locality 3 on Little Dixie Wash (Fig. 2, #43), the basal black mat is capped by silty clay that displays a light brownish-gray lower portion and a gray upper portion (Stratum II-6Cu and 6Ab, respectively) with few, small iron-oxide mottles in both horizons. Bulk organic carbon from the 6Ab horizon dated to 11,695 cal BP. This stratum is capped by an alluvial deposit of light brownish-gray silt and fine sand displaying common iron-oxide mottles. It fines upward into grayish-brown silty clay with fewer mottles and weak soil development (Stratum III-5Cox and 5Ab, respectively). Bulk organic carbon from the 5Ab horizon at Locality 3 dated to 11,690 cal BP, almost identical to the age of the underlying 6Ab horizon. A similar date of 11,745 cal BP was also obtained from bulk organic carbon in the lowest stratum at Locality 1 on Little Dixie Wash (Fig. 2, #42), a gray silty-clay 3Ab horizon. The underlying horizon at locality 1 was also distinguished by common iron-oxide

nodules and staining characteristic of periodic saturation and drying.

Stratum IV at locality 3 on Little Dixie Wash consisted of light brownish-gray silty loam, fining upward into grayish-brown silty clay (4Cu and 4Ab, respectively). A weakly developed soil marks the upper boundary of Stratum IV. Three, dilute-water, spring-related ostracodes were identified in this deposit: *F. acuminata*, *E. meadensis*, and *Cypridopsis okeechobei* (Table 3). In addition, four semi-aquatic gastropods occur in the same horizon: *Pseudosuccinea columella*, *H. newberryi*, *G. parvus*, and *Fossaria parva* (Table 2). A radiocarbon date on bulk organic carbon from the 4Ab horizon of Stratum IV indicates a perennial, groundwater-fed wetland developed in the wash by 11,480 cal BP.

Stratum IV at locality 3 is covered by another fine-grained alluvial deposit composed of light yellowish-brown loamy sand that fines upward into light grayish-brown silty clay (Stratum V-3Cu and 3Ab, respectively). The upper portion of this stratum displays a weakly developed soil containing the shells of the semi-aquatic snail *F. parva* (Table 2). A date of 10,705 cal BP was obtained from bulk organic carbon in the 3Ab horizon.

At Locality 1 on Little Dixie wash, the basal black mat (Stratum I, 3Ab Horizon) is also capped by a deposit of fine sandy loam displaying a buried soil profile (Stratum II, 2Ab Horizon). Shells from the semi-aquatic gastropod *H. newberryi* were identified in the 2Ab Horizon characteristic of a perennial wetland habitat (Table 2). Bulk organic carbon and a *H. newberryi* shell from this horizon dated to 10,945 cal BP and 11,485 cal BP, respectively.

At Dove Springs wash, the middle and upper black mats reported by Pigati et al. (2012) included succineid gastropods. Samples of these shells were dated to 11,820 and 11,375 cal BP, respectively, corresponding closely to the sequence of organic horizons recorded in Little Dixie wash at localities 1 and 3.

4.4. 10,300–7200 cal BP

The period after 10,300 cal BP records another change in hydrological conditions, marked by the activation of local alluvial fans and a cessation of fine-grained deposition and black mat development in Indian Wells Canyon and Little Dixie Wash, characteristic of declining groundwater levels. Groundwater-related deposits are restricted to lower elevations in Rose Valley and possibly Dove Springs Wash.

In Rose Valley, the north borrow pit contains a sequence of vertically stratified channel, floodplain, and eolian deposits exposed in a 5-m-thick section (Fig. 2, #46). The basal stratum (Stratum I-4Cu4) consists of coarse sand with weakly sorted and poorly bedded subangular to well-rounded gravel and cobbles characteristic of an alluvial fan deposit. This stratum is overlain by a relatively thin layer of fine, well-sorted sand containing a dark organic silt lens (Stratum II-3Cu3). A radiocarbon date from bulk organic carbon in the 3Cu3 Horizon of Stratum II suggests a transition from high-energy to lower-energy depositional conditions on the fan by about 9810 cal BP. Three species of dilute water micro-invertebrates were identified in the 3Cu Horizon, including the ostracodes *Ilyocypris bradyi* and *F. acuminata* and two specimens of the gastropod *Tryonia* sp. (Tables 2 and 3), implying a spring-fed perennial wetland with nearby ground-water source.

At the Lava End locality in Rose Valley, the upper black mat (Stratum III- 3AOb1), dated to 9065 cal BP (bulk organic carbon), is capped by a fining-upward deposit of coarse-sand to loamy sand that displays a weakly developed buried soil (Stratum IV-2Ab/2Cu). Internal sorting and bedding are consistent with an alluvial origin for Stratum IV. Radiocarbon dates of 7625 cal BP and 5075 cal BP from bulk organic carbon in the buried soil (2Ab horizon) indicate deposition of Stratum IV occurred after 9065 cal BP, but before

7625 cal BP. Alluvial deposition near the end of the early Holocene is also indicated at nearby Rose Valley flat where a surface playa of fine sand and silt, overlies a thin, organic-rich buried soil (2Ab Horizons) formed in silty-clay (Fig. 2, #52) that yielded a date of 8130 cal BP on bulk organic carbon.

On the flanks of the eastern Sierra Nevada in Indian Wells Canyon, activation of the local alluvial fan is indicated by a deposit of poorly sorted and well-bedded sand that grades into grayish-brown loamy sand (Stratum VIII-2Ab/2Cu). Bulk organic carbon from a well-developed buried soil at the upper contact of Stratum VIII dated 9810 cal BP. Based on the age of the underlying buried soil (Stratum VII, 3Ab horizon), deposition of Stratum VIII occurred sometime between 11,190 and 9810 cal BP.

At Locality 5 on Little Dixie Wash (Fig. 2, #45), an inset alluvial fan at the confluence with Freeman Gulch records at least six episodes of deposition during the early and middle Holocene. The lower four strata (Stratum I-IV) consist of coarse sand that fines upward into sandy loam (Stratum I), sandy clay loam (Stratum II and IV), or silty clay loam (Stratum III), each displaying weakly developed soils along the stratum's upper boundary. The presence of a few small angular to subrounded gravels in Stratum I, II, and IV, and small to medium, angular to subrounded gravel in Stratum III, is typical of local alluvial fan deposits. Iron-oxide mottles also occur in the Ab horizons of Stratum I and III, and the lower part of Stratum II (5Cox horizon), suggesting periodic groundwater saturation. A radiocarbon date of 7225 cal BP was obtained from bulk organic carbon in the 4Ab horizon of Stratum III, while a slightly earlier date of 7825 cal BP was generated from bulk organic carbon in the overlying 3Ab Horizon of Stratum IV.

Along Dove Springs Wash, early to middle Holocene deposits were not directly dated, although Strata III-VIII are characteristic of this interval, including several fine-grained alluvial deposits with organic-rich horizons. These deposits underlie Stratum IX which consists of coarse sand that fines upward into sandy clay loam (Stratum IX- 5Cu). Bulk organic carbon from a dark grayish-brown soil (5Ab) at the top of Stratum IX returned a radiocarbon date of 4755 cal BP and contained an abundant ostracode assemblage (Table 3). Four spring and stream related species were identified including *E. meadensis*, *I. bradyi*, *F. acuminata*, and *C. vidua*.

4.5. Synthesis of surface and groundwater records from inflow drainages

Alluvial strata preserved along drainages entering China Lake basin provide a record of successive hydrological changes from the terminal Pleistocene to early Holocene. The record begins prior to the formation of the lower black mat in the South Borrow Pit in Rose Valley, around 13,400 cal BP. This mat sat upon coarse sand, gravel, and cobble deposits that were sorted and bedded within an active channel under high-energy fluvial conditions not recorded in later-dating deposits from Rose Valley. We interpret these fluvial deposits as bed-load of the former Owens River, suggesting significant water flow prior to 13,395 years ago. The timing is consistent with a minimum constraining age of 12,635 cal BP for high energy fluvial deposits downstream at Fossil Falls. In contrast, basal strata from inset terraces along Sierra Nevada drainages consistently date to the Younger Dryas between about 12,600 and 12,000 cal BP, and post-date the interval of high-energy water flow and channel activity in Rose Valley. Since all of the terminal Pleistocene and early Holocene deposits represent discontinuous terraces set within older fans, the absence of earlier alluvial terraces implies that erosional processes (i.e., channel incision and lateral migration) prevailed in these drainage systems prior to 12,600 cal BP and stream flow was sufficient to evacuate suspended sediments.

When the lower Owens River and Sierra Nevada drainage records are viewed together, it appears that surface runoff and stream flows were generally greater before 13,400 cal BP, with high-energy flows and erosive conditions persisting no later than the early part of the Younger Dryas (~12,800–12,700 cal BP). A shift in the depositional regime occurred by 12,600 cal BP, allowing fine-grained sand, silt, and clay to accumulate within medial drainage systems. The interval between about 12,600 and 10,400 cal BP is marked by multiple short, low-energy depositional pulses, each separated by periods of stability and wetland formation. The timing of these processes is quite similar between all studied drainages. The earliest fine-grained deposits with organic horizons, dating between about 12,600 and 12,100 cal BP, were identified at Fossil Falls on the Lower Owens River, at Little Dixie Wash localities 3 and 4, and at Dove Springs Wash. Black mats dating between 11,985 and 11,690 cal BP are recorded in Little Dixie Wash, Dove Springs Wash, and Indian Wells Canyon. The Lower Owens River channel and all three Sierra Nevada drainage systems record a subsequent period of deposition and organic mat formation between 11,480 and 11,195 cal BP.

These same general conditions persisted well into the early Holocene. After another pulse of deposition, organic-rich horizons and mesic habitats once again developed between about 10,900 and 10,400 cal BP in Rose Valley and Little Dixie Wash. This suggests that effective moisture during the first millennia of the Holocene was at least as high as the last millennium of the Pleistocene. Yet, despite persistent wet conditions, the fine-grained nature and sequential pulsing of deposition imply only periodic, low-energy surface flows in the lower Owens River system and eastern Sierra drainages. This, in turn, indicates no significant or sustained sources of surface flow from these drainages into China Lake basin after ~13,395 cal BP.

5. Discussion

5.1. Pluvial China Lake and related lacustrine records

The timing and magnitude of lake-level fluctuations documented in China Lake basin corroborate evidence previously described by Bacon et al. (2006) for abrupt, high amplitude changes in water balance within the Owens River system during the terminal Pleistocene, coincident with rapid shifts in paleoclimate records from the North Atlantic (Fig. 8; Benson et al., 1996, 1997, 2013; Phillips et al., 1996). Although Bacon et al. (2006) found no evidence that Owens Lake overflowed into the lower Owens River after ~15,300 cal BP, the China Lake record suggests that Owens River input was responsible for three subsequent lake-level oscillations of sufficient magnitude to overtop the sill and spill into Salt Wells Valley (see also Orme and Orme, 2008). The most significant of these high water episodes occurred at ~14,100 cal BP when China and Searles lakes merged and reached an altitude of no less than 668–678 m asl. A subsequent oscillation less than 1000 years later, between 13,385–13,200 cal BP, marks the final time China Lake spilled into Searles basin and perhaps the final time Owens Lake spilled into the lower Owens River channel. The age of high energy fluvial deposits (i.e., bedded and sorted cobbles and gravels) in Rose Valley is consistent with the timing of this termination, as no evidence suggests substantial surface flows after ~13,395 cal BP. Both of these terminal Pleistocene high stands in China Lake basin are paralleled almost precisely by high water episodes in Owens Lake (Fig. 8; Bacon et al., 2006; see also Orme and Orme, 2008). Moreover, evidence from China Lake basin documents two earlier high stands. The first of these occurs at about 17,000 cal BP or shortly thereafter (Fig. 8), filling a 2000 year-long gap in the shoreline and

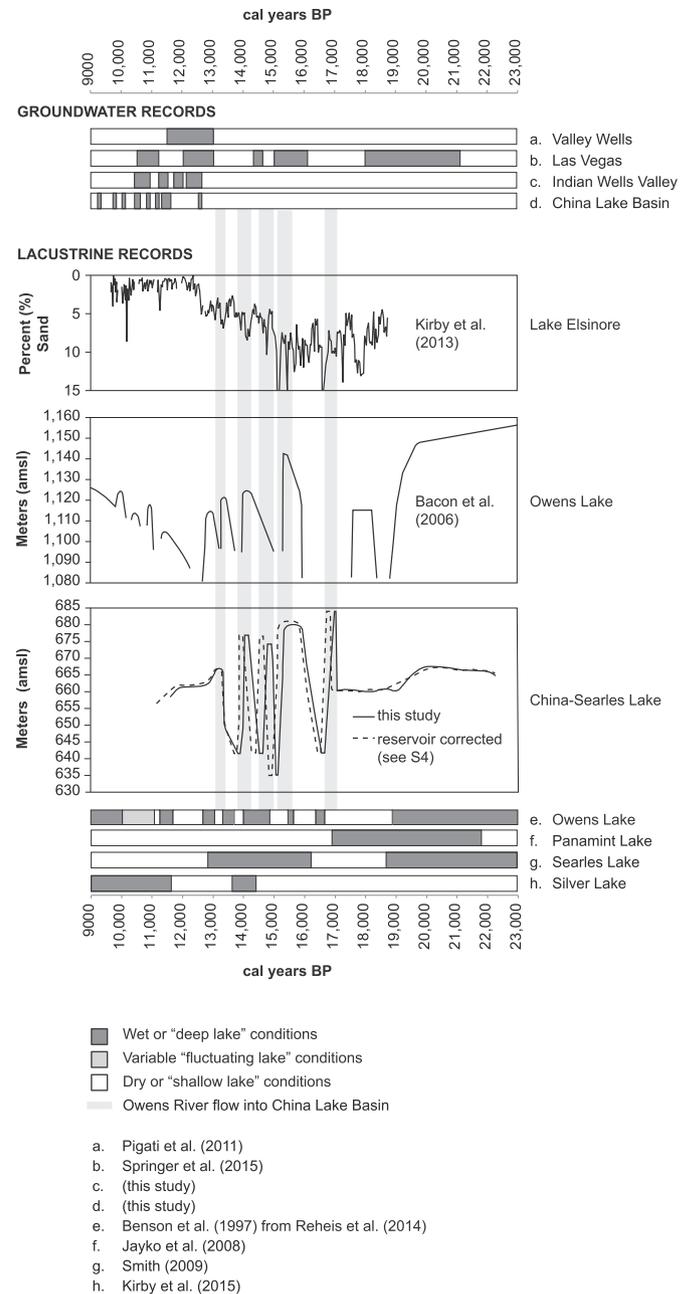


Fig. 8. Comparison of regional lake level curves and groundwater records showing a high level of correspondence between pluvial events during the late Pleistocene.

sedimentary record from Owens Lake (Benson et al., 1996, 1998; Bacon et al., 2006; Fig. 3). This latter oscillation corresponds to high-water episodes in other large and small lakes in the northern Great Basin ~17,000 cal BP (Munroe and Laabs, 2012). A subsequent China Lake high-stand at 14,980 to 14,880 cal BP seems to correlate with deep lake conditions in Owens Lake reported by Benson et al. (1997) beginning about 14,900 cal BP, but is not apparent in the outcrop record of Bacon et al. (2006; Fig. 8). Likewise, a high-elevation lake in Owens basin around the last glacial maximum (~22,000 cal BP) is not evident in the downstream basin of China Lake, perhaps indicating that the Owens sill was higher during the late Pleistocene (Orme and Orme, 2008), or the altitude of the “soft” sill with Salt Wells Valley was much lower.

In Searles basin, the coarse resolution of the terminal Pleistocene sedimentary record reported by Smith (2009: Fig.39) makes specific correlations with high amplitude lake-level oscillations difficult. Smith (2009) recognizes comparatively low water levels and decreased inflow between ~18,760 and 16,250 cal BP, similar to generally low water levels recognized in China Lake basin over a similar time span. The apparently rapid ~17,000 cal BP transgression and coalescence with China Lake is not evident in the existing Searles Lake record. However, this oscillation does correspond to an Owens River-fed lake in Panamint Valley that persisted as recently as 17,195 to 16,970 cal BP (Fig. 8; Jayko et al., 2008). That Panamint Lake had receded for the last time by 14,925 cal BP (Jayko et al., 2008; Jayko and Meyer, 2011), suggests that Searles Lake may not have reached the altitude of its overflow sill at 690 m amsl again after ~17,000 cal BP (*contra* Garcia et al., 1993; Lin et al., 1998; Smith, 2009: Fig. 39; Smith and Street-Perrott, 1983: Fig. 10.5). This is consistent with the maximum documented altitude of post-17,000 cal BP lake-stands in China Lake basin.

Increased inflow and generally high lake levels are recorded in Searles basin from about 16,250 cal BP to the beginning of the Younger Dryas at 12,865 cal BP. China Lake basin shows four intervals of high water and coalesced lakes during this same time span, between ~16,000 and 15,300 cal BP, ~14,980 to 14,880 cal BP, ~14,200 to 14,100 cal BP, and again ~13,385 to 13,200 cal BP, separated by extended periods of low water levels. The earliest of these oscillations is also consistent with evidence for high stands in lakes Lahontan (Benson et al., 2013) and Bonneville (Oviatt, 2015) at ~15,300 to 15,500 cal BP. A decline in effective precipitation after ~15,500 to 15,000 cal BP is documented in the northwestern Mojave Desert by a shift from Juniper woodland to sagebrush-dominated steppe in the pollen record from Owens Lake (Mensing, 2001), and by decreasing sedimentation rates west of the Sierra Nevada in Tulare Lake at a similar latitude (Blunt and Negrini, 2015). This change roughly corresponds to the end of the Older Dryas and beginning of the Bølling Allerød in Greenland (e.g., Svensson et al., 2008), and is reflected in a number of other paleoclimate records from the southwestern U.S. (e.g., Hendy et al., 2002; Heusser et al., 2015; Kirby et al., 2013, 2015; Springer et al., 2015).

Although lacustrine records from the Mojave River system have variable resolution for the terminal Pleistocene and early Holocene, generally high, but fluctuating water levels are recorded at Lake Mojave until about 13,200 cal BP (Wells et al., 2003), consistent with the timing of the last spill-over at China Lake. The high-water event in China Lake basin at ~14,200 to 14,100 cal BP correlates with a high stand at Silver Lake between ~14,400 and 13,600 cal BP, although three earlier lake-level fluctuations in China Lake basin are not matched by the Silver Lake record (Fig. 8; Kirby et al., 2015). Lastly, there is a correspondence between high-amplitude lake-level fluctuations in the Owens River system between 17,000 and 13,200 cal BP and spikes in the deposition of sand at Lake Elsinore in the San Bernardino Mountains (Fig. 8), attributed to increased surface run-off and stream flow from more frequent and/or higher magnitude winter storms (Kirby et al., 2013).

5.2. Surface and groundwater records from the Mojave Desert and the timing of fan activation

Between about 12,600 and 10,500 cal BP, water discharge into local washes appears to have been regular, but episodic, reflected by similar sequences of stratified sand, silt and organic-rich horizons preserved as inset terraces at Little Dixie Wash, Dove Springs Wash, and Indian Wells Canyon, and along the Owens River channel in Rose Valley. At least three cycles of surface water discharge are recorded during the terminal Pleistocene and early Holocene. The

first two pulses occurred between ~12,600 and 12,300 cal BP, and 12,000 to 11,800 cal BP. A third widespread interval is also recognized in Rose Valley and all three Sierra Nevada drainage systems between 11,480 and 11,195 cal BP. The early Holocene brought a repeat of this pattern as a depositional pulse after ~11,200 cal BP was followed by the emergence of habitats supporting freshwater mollusks and the development of organic-rich horizons by ~10,700 cal BP in Little Dixie Wash. Deposition of fine-grained, clay-rich silts dated between 10,600 and 9065 cal BP at the Lava End locality in Rose Valley also reflects comparatively high groundwater into the early Holocene.

In China Lake basin, a similar sequence of widespread groundwater-related spring pools and organic-rich black mats occur at elevations between about 680 and 665 m amsl beginning during the terminal Pleistocene and continuing into the early Holocene. An initial episode of groundwater discharge is documented at archaeological site KER-6966 and the Alrite Pit where spring deposits each date to 12,635 cal BP. A second widespread episode of elevated groundwater occurred between ~11,700 and 11,200 cal BP, identified at the Basalt Ridge locality (Basgall, 2004), paleo-Lark Seep spring complex (Couch, 2003), and several locations along the Owens River tributary on the northwestern edge of the basin. These include archaeological sites KER-5611, KER-6962, the TO 39 localities, and the Baker Borrow Pit. Organic-rich horizons at several other locations in the basin suggest high groundwater levels persisted until at least 10,000–9300 cal BP.

Paleohydrological records from China Lake basin are consistent with region-wide evidence for high groundwater levels and increased spring discharge in the Mojave Desert during the terminal Pleistocene and first part of the Holocene (Fig. 8; e.g., Meyer et al., 2011; Pigati et al., 2011; Springer et al., 2015; Quade et al., 1998). Previous research demonstrates that groundwater in Indian Wells Valley is partially recharged by extra-local sources on the Kern Plateau, west of the Sierra Nevada crest (Güler and Thyne, 2004, 2006; Ostidick, 1997). This suggests that elevated groundwater levels in Indian Wells Valley during the terminal Pleistocene and early Holocene were, in part, related to snow pack on the opposite side of the Sierra Nevada, rather than simply local sources within the watershed. This is also indicated in the Mojave River drainage, where source areas in the San Bernardino Mountains continued to deliver episodic surface flows through the Intermittent Lake III Period (Wells et al., 2003), dated between 13,000 and about 9800 cal BP. Further east in the Mojave Desert, groundwater-related deposits from Valley Wells and Las Vegas Valley indicate that water levels declined after the Younger Dryas (12,900–11,600) and, like the record from Indian Wells Valley, reflect only intermittent discharge into the early Holocene, decreasing substantially after ~10,900 to 10,630 cal BP (Fig. 8; Pigati et al., 2011; Springer et al., 2015).

During the early Holocene, a major geomorphic transition is apparent in Indian Wells Valley and across the Mojave Desert, represented by the accumulation of coarse-grained, alluvial fan deposits which now form expansive piedmonts along valley margins. Terminal dates for buried wetlands at Little Dixie Wash, Indian Wells Canyon, and the Baker Borrow Pit in China Lake basin, indicate widespread fan deposition began after 10,900 to 10,700 cal BP, following an extended period of soil formation on fan surfaces. The timing of this transition is further supported by dated fan complexes on the western side of Indian Wells Valley and in Koehn Lake basin to the south (the outflow to Dove Springs Wash), where early Holocene fan deposition is marked by buried soils dated to 10,245 and 10,640 cal BP, respectively (Young, 2007, 2009). Widespread fan rejuvenation during the early Holocene is well documented elsewhere in the Mojave Desert (Harvey et al., 1999; McDonald et al., 2003; Miller et al., 2010) and has been attributed to

declines in vegetative cover and a shift from mainly winter to summer (monsoonal) precipitation (Miller et al., 2010). This is also reflected by the dominance of desert shrubs in the Owens Lake pollen record beginning after ~11,000 cal BP (Mensing, 2001).

5.3. Implications for early human occupation

The pluvial Owens–Searles system was in substantial decline by the beginning of the Clovis Period (ca. 13,500 to 12,900 cal BP), but a low-elevation lake persisted in China Lake basin through much of

this interval. Human occupation of the basin is bracketed on the early end by the last significant high-stand lake (dated to ~14,100 cal BP) which reached an altitude of at least 678 m amsl, submerging most of the basin with Owens River water (Fig. 9). Recent evidence from the northern Great Basin leaves open the possibility for a pre-Clovis human presence in the Mojave Desert before 14,100 cal BP (e.g., Gilbert et al., 2008). However, if evidence from this period is preserved at China Lake, it lies above an altitude of ~678 m amsl, or has been reworked or buried at lower altitudes by the 14,100 cal BP lake transgression.

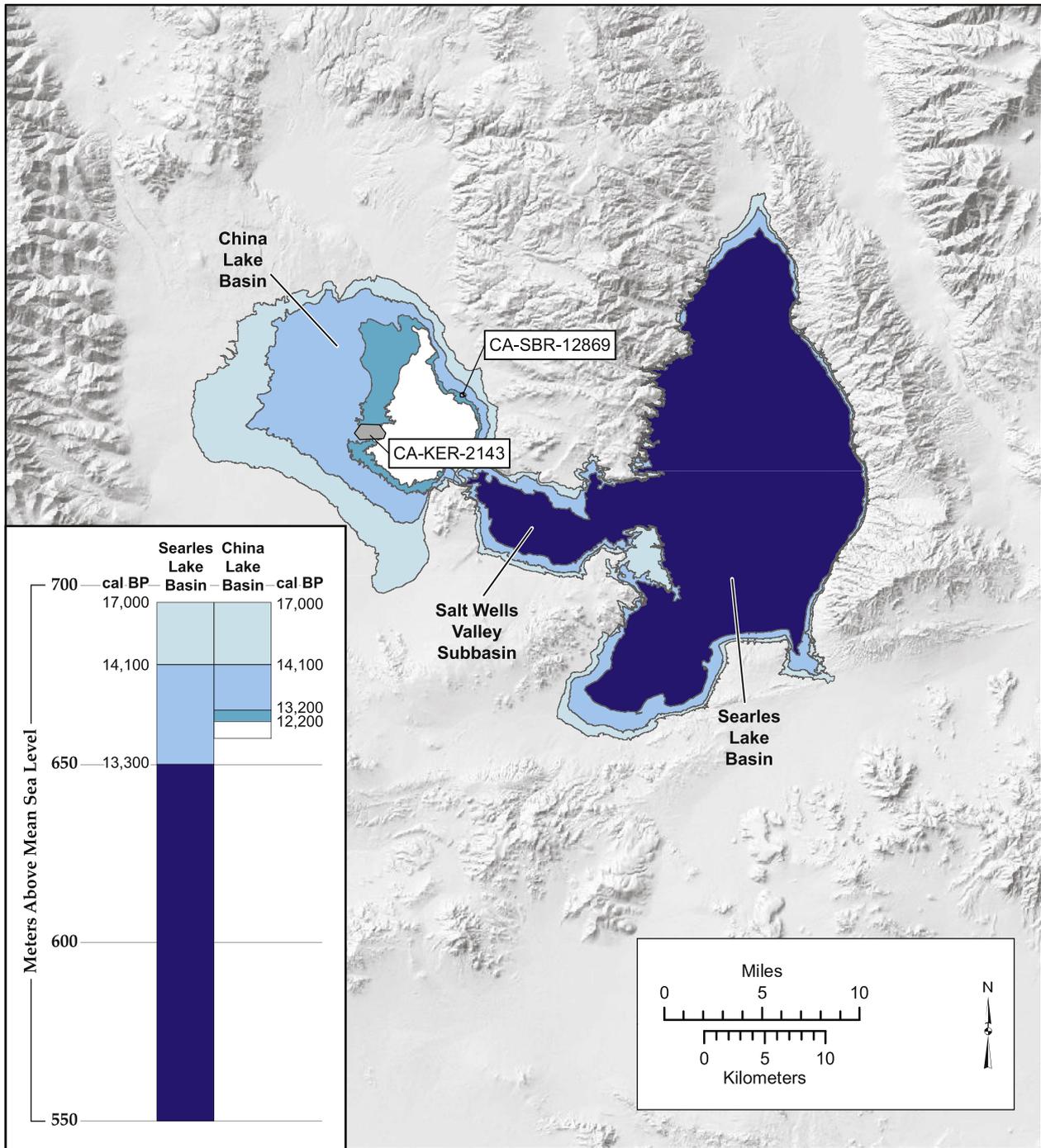


Fig. 9. Spatial extent of high-stand lakes in China Lake and Searles basins at different times during the late Pleistocene based on minimum lake altitudes shown in Fig. 4. Past lake levels indicate that archaeological sites SBA-12869 and KER-2143 would have been submerged at 14,100 cal BP and between ~13,385–13,200 cal BP.

Table 5
Count of Terminal Pleistocene-Early Holocene Projectile Points and other Tools from SBR-12896 and KER-2143.

	SBR-12,869 ^a (661–662 m)	KER-2143 ^b (662–665 m)
Great Basin Stemmed Projectile Points	139	44
Fluted/Non-fluted, Concave Base Projectile Points	–	37
Crescents	5	41
Bifaces	261	243
Formed Flake Tools	456	334
Cores/Core Tools	28	38

Notes: m – meters above mean sea level.

^a Giambastiani and Bullard (2007).

^b Basgall (2007).

Substantial assemblages of early projectile points, crescents, and other early tool forms have previously been documented at ~665–661 m amsl by Emma Lou Davis at her Stake locality (KER-2143; Davis and Panlaqui, 1978; see also Basgall, 2007; Rondeau, 2004) and by Giambastiani and Bullard (2007) at site SBR-12869 (Table 5). Both of these localities may have been available for human use when lake levels were lowered between ~14,000 and 13,385 cal BP, at the very beginning of the Clovis Period (Waters and Strafford, 2007). However, by 13,385–13,200 cal BP, a lake had reformed and reached the outflow sill at a minimum elevation of 665 m amsl (Fig. 9). This lake would have precluded occupation at both SBR-12869 and KER-2143. During the Younger Dryas, after 13,000 to ~12,000 cal BP, a low-elevation, groundwater-fed lake stood at or below a maximum elevation of 661–662 m amsl (Fig. 9). This suggests that the most probable period of occupation at both SBR-12869 and KER-2143 was during the Younger Dryas or early Holocene, following the Clovis-age high stand (Giambastiani and Bullard, 2007). The slightly higher elevation of KER-2143, and presence of fluted and unfluted Concave-base projectile points (not identified at SBR-12869; Table 5), may indicate the Stake Locality is older than the other site, dating before ~12,200 cal BP.

While any conclusions regarding the earliest human use of China Lake basin awaits direct dating of the cultural deposits, lacustrine and groundwater records reported here show that lake levels fell rapidly for the last time after 14,100 cal BP and only a small, low-elevation lake existed in the basin through the terminal Pleistocene (Fig. 9). Consequently, widespread evidence for early human use above the 665 m amsl shoreline is related to post-lake spring, wetland, and other groundwater-fed environments that existed throughout the basin during the Younger Dryas and early Holocene. In these upper elevations, spatial convergence between former shorelines and human tools is only coincidental. The lack of mesic habitats younger than ~9300 cal BP suggests human occupation likely declined thereafter, consistent with very rare evidence for middle and late Holocene (<8200 cal BP) human use of the basin (Basgall, 2007; Byrd, 2006; Rosenthal et al., 2001). If a reservoir correction is necessary for the carbonate-based dating of lacustrine deposits used here, then the last high-stand lake may be 140–350 years or more later in time, pushing initial human use of the basin squarely into the Younger Dryas. Moreover, the remains of megafauna, which are widespread in China Lake basin below 665–663 m amsl, could have only accumulated prior to the high lake stand at 14,100 cal BP, or during the brief recessive phase ending no later than ~13,385 cal BP, before the final extinction of these species (ca. 13,000 cal BP; Faith and Surovell, 2009; Surovell et al., 2016). This suggests that coeval use of the lower basin with humans was unlikely, but possible.

6. Conclusions

Analysis of the paleohydrological record from Indian Wells Valley documents a three-part sequence during the terminal Pleistocene and early Holocene that strongly correlates with other geomorphic and fluvial records from the Mojave Desert. During the terminal Pleistocene, lake levels in Owens, China Lake, and Searles basins oscillated rapidly, reaching high stands at least five times between 18,000 and 13,000 cal BP, in concert with other pluvial lakes in the desert west. A low elevation, groundwater-fed lake persisted in China Lake basin through the first part of the Younger Dryas until at least 12,000 cal BP. Although portions of the basin below an altitude of 665 m amsl were available for human occupation at the beginning of the Clovis Period (~13,500–13,385 cal BP), initial use of this zone likely began after 13,200 cal BP. Above an altitude of 665 m amsl, groundwater-related habitats, including spring pools, and other wetlands, were the primary focus of human occupation after 14,100 cal BP. By ~9300 cal BP groundwater declined and mesic habitats dried, redirecting human occupation to more productive localities in the region.

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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.quascirev.2017.04.023>.

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