DATA RECOVERY AT PREHISTORIC SITE CA-RIV-6896/6897 (33-011573/33-011574)

Comprehensive Final Report of Archaeological Investigations for the I-10/Jefferson Street Interchange Improvement Project and the Varner Road/Jefferson Street Improvement Projects in the City of Indio, Riverside County, California

08-RIV-10 PM R51.7/R53.1 (KP R83.2/R85.5)
EA 08-475200 / PN 0800000755

VOLUME II: APPENDICES A–V

Submitted To
California Department of Transportation
District 8, San Bernardino

On Behalf Of
City of Indio
and
County of Riverside

April 2017

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Michael J. Moratto and Dennis McDougall
Applied EarthWorks, Inc.

VOLUME II

APPENDICES A–V

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APPENDIX C

Preliminary Report: Microinvertebrates and Gyrogonites from Lake Cahuilla, California

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MICROINVERTEBRATES AND GYROGONITES FROM LAKE CAHUILLA, CALIFORNIA

Abstract

The combined analysis of ostracodes, mollusks (microinvertebrates), and calcareous algae (gyrogonites) constitutes a powerful tool for reconstructing ancient lacustrine environments. Lake Cahuilla, California, offered a unique opportunity to study the aquatic system generated by the intermittent diversion of the Colorado River into the Salton Trough over the past 2000–3000 years. This investigation elaborates on possible scenarios that best describe the ecology of several of the Lake Cahuilla high stands.

INTRODUCTION

Micropaleontology is a powerful tool for reconstructing the paleoenvironmental history of aquatic environments. Diverse and abundant microinvertebrates (ostracodes and mollusks) and calcareous algae are common in nonmarine environments where they are sensitive to variations in pH, temperature, salinity, and water chemistry, among other factors.

Ostracodes are microscopic crustaceans characterized by a hinged bivalve carapace made of calcite ranging in size between 0.5 and 2.0 mm. The carapace is the only body part that is preserved in the geologic record (Horne et al. 2002; Pokorný 1978). In continental waters they are mostly benthic (crawlers), although some species are nektic (swimmers) and may swim around the vegetation (Forester 1991). This group colonized continental aquatic systems as early as the Carboniferous but has thrived in the oceans since the Cambrian. Today, ostracodes are diverse and abundant in marine and nonmarine environments. Paleontologists have devoted more time to the study of ostracodes than have biologists; hence the ecology of ostracodes is poorly understood. Recent progress on the application of ostracodes as indicators of hydrogeologic variations, however, calls for additional studies of the ecology of springs and seeps as well as their associated wetlands or cienegas (De Deckker 1983; Forester 1983, 1986; Holmes and Chivas 2002; Palacios-Fest 1994, 2008; Palacios-Fest et al. 1994, 2001).

Mollusks associated with the ostracode fauna are also an important element in paleolimnological analysis. Mollusks include the bivalve clams and mussels (Bivalvia) and the univalve snails (Gastropoda). Mollusks are soft bodied and unsegmented, with a body organized into a muscular foot, a head region, a visceral mass, and a fleshy mantle that secretes a shell of proteinaceous and crystalline calcium carbonate (aragonite) materials. Both marine and nonmarine species exist. The nonmarine species, which are the subject of this study, include several families of aquatic snails (Physidae, Planorbidae, and Valvatidae). The associations of mollusks in sediments reflect the water quality, salinity, and streamflow (Dillon and Stewart 2003; Rutherford 2000). For example, the occurrence of juveniles alone in a sample is interpreted as the introduction of early-stage individuals during warm or warming months (Rutherford 2000). If the population reaches stability and adults are encountered, then it is assumed that the feature held water for a relatively prolonged period. Some species, such as *Pisidium* sp., require well-oxygenated lotic (flowing) waters and prefer neutral to alkaline pH but cannot tolerate organic pollution present in the marsh. By contrast, other species, such as *Physa humerosa*, can tolerate poorly oxygenated (but not disoxic) lentic (standing) waters and can tolerate some organic pollution and eutrophic conditions (Dillon and Stewart 2003). The latter species prefer lakes, wetlands, ponds, and the calmest areas of coastal rivers. Like the ostracode signatures, the signatures of mollusks are used in this study to integrate the paleoecological characteristics of Lake Cahuilla adjacent to archaeological site CA-RIV-6896/6897.

Last, but not least important, the occurrence of calcareous algae (gyrogonites) offers insight on colonization and environmental parameters of a lake. The Characeae or Charophyta are gyrogonites that are a strange, isolated group of aquatic plants growing entirely underwater. Modern species prefer ponds or lakes, although they are occasionally found in running water, and are partial to somewhat brackish conditions, such as freshly dug ditches in marshes near the sea. In deeper environments subject to increasing stream flow, they soon give way to more vigorous vegetation, such as cattails (*Typha* sp.). They commonly pioneer the colonization of habitats such as recently dug canals and ditches (Allen 1950). Ecologically, the Charophyta promote water clarity, enhance fish populations, and stabilize the bottom surface. In clear, still water, masses of orange-red antheridia (the male reproductive organs) are abundant and visible (Allen 1950). The average height of these plants is 30–46 cm, but some individuals are just a few centimeters tall. Usually, charophytes grow in shallow waters (less than 60 cm deep), but sometimes they occur at much greater depths (e.g., 3–12 m at Lake Garda, Italy; Allen 1950; Bolpagni et al. 2013). Many modern charophytes have a short growing season between spring and late summer, when temperatures are warm and just before the aquatic system dries out (Allen 1950). Gyrogonites are used in this study to complement the microinvertebrate record.

Among the studies of Lake Cahuilla, the earliest reports date from 1853 when Lt. R. S. Williamson and his party conducted the first geological survey of the Salton Sink, exploring for railroad routes (Blake 1858). Blake (1858), the geologist in the group, recognized that the Salton Sink was below sea level and later (1914) he inferred that a lake had formed in the basin in the past. He called this Lake Cahuilla in honor of the indigenous inhabitants of the region.

The first reports of fossils include Miocene marine forms found in the Carrizo Gorge area in San Diego County, California, by Blake (1914), who assumed that the lake was the northern extension of the Gulf of California. Free (1914) instead proposed that it was a freshwater lake that accumulated sediments from the surrounding highlands. To support his hypothesis, Free identified nonmarine snails (*Hydrobia protea* Frauenfeld and *Physa humerosa* Gould) buried in the sediments. Other Lake Cahuilla studies include Bowersox (2003), Waters (1983), Wilke (1978), and Philibosian et al. (2011).

Lake Cahuilla, however, is also rich in archaeological evidence of lake level fluctuations. For example, Wilke (1978:90–93) found—through radiocarbon dates, historical accounts, and cross-dating of artifacts—three lacustrine intervals leaving distinctive to subtle shorelines during the past 2,100 years. The earliest of these was dated to approximately 2,100 to 1,400 years ago, the second between 1,100 to 750 years ago, and the last stand between 700 and 500 years ago. Waters (1983:382–385) refined Wilke's interpretation and recognized at least four lacustrine high stands reaching the 12.8-m shoreline during the last 1,500 years. More recently, Philibosian et al. (2011) summarized Waters research and, based on extensive stratigraphic trenching and numerous radiocarbon dates, refined his lacustrine model identifying six high-stand intervals between A.D. 790 and 1700. Another summary of the Philibosian et al. (2011), Waters (1983), and Wilke (1978) is presented by Moratto (2011). None of these studies makes reference to the biological content of Lake Cahuilla other than some anecdotal notes.

The primary purpose of this report is to document the microinvertebrate and calcareous algae composition of several Lake Cahuilla lacustrine intervals to preliminarily reconstruct, based on two fossiliferous and two unfossiliferous samples, the paleoecological characteristics of the lake between approximately 400 B.C. and A.D. 1600.

AREA OF STUDY

As part of its archaeological investigations in 2013 at CA-RIV-6896 (now recognized as part of a larger single site, CA-RIV-6896/6897), Applied EarthWorks, Inc. opened 29 backhoe trenches, called “mechanical excavations” (MECs), at and near the site. CA-RIV-6896 is situated immediately east of Jefferson Street and north of Interstate 10 (I-10) in the City of Indio, Riverside County, California (see this report: Figures 1-1 and 1-2). The site is within the Area of Potential Effects (APE) investigated by Applied EarthWorks, Inc. in an effort recover data from the site (a historic property eligible for the National Register of Historic Places) prior to construction of highway and road improvements (see Chapter 1).

MATERIALS AND METHODS

Four samples from MECs 13-15A and 13-13E at site CA-RIV-6896, near the 12.8-m high stand of Lake Cahuilla were analyzed for microinvertebrates to make a preliminary reconstruction of the lake’s environmental history. The sediment samples were prepared using routine procedures (Forester 1988) modified by Palacios-Fest (1994). Samples were air-dried, weighed, and soaked in boiling distilled water with 1 g of Alconox to disaggregate the sediments. Then they were left to sit at room temperature for 5 days and were stirred once a day during that period. Using a set of three sieves, the samples were wet-sieved to separate the coarse (>1 mm), medium (>106 micrometers or microns [μm]), and fine (>63 μm) sand fractions to help identify the system’s paleohydraulics. The very fine sand and silt and clay fractions were washed away at this stage. Therefore, the particle-size analysis departs from the formal U.S. Department of Agriculture (USDA 2003:207–209) procedure and it is used only as a rough reference in this study. It is important to highlight that the possible discrepancy between the approach used in this investigation and that of the USDA is the result of grouping the very fine sands with the finer fractions, which in fact changes the total percentage of sand but does not affect the actual behavior of sands in the ecosystem. The value of the approach used here is that it provides a quick and easy way to process the data and to estimate the patterns of water discharge into the aquatic system over time. More detailed particle-size analysis may be conducted using the appropriate research methods. The particle-size data are shown in Table C-1. Table C-2 shows the mineralogical composition of the four samples.

The four samples were analyzed under a low-power microscope to identify fossil contents and faunal assemblages (Table C-3). Mollusks, ostracodes, and/or gyrogonites of calcareous algae occurred in three of the four samples (Tables C-4–C-7). Ostracodes (Table C-4) occurred in two samples, ranging in abundance from extremely rare to extremely abundant (>2,300 total; exceeding the statistical 300 count) (Table C-5). Mollusks (Table C-7) were recorded in three samples ranging in abundance from extremely rare to extremely abundant (7–1040) (Table C-6).

Table C-1
Sample Identification Numbers, Stratigraphic Position, Bulk and Residual Weight, and Lithological Characteristics of Materials Analyzed for Site CA-RIV-6896 on the High-stand Shoreline of Ancient Lake Cahuilla

Sample ID (MEC)	Age (B.C./A.D.)	Lake Interval	Elevation (m bs)	Bulk Wt. (g)	Fraction Wt. (g)	>1 mm (g)	>106 m (g)	>63 mm (g)	<63 mm (g)	>1 mm (%)	>106 mm (%)	>63 mm (%)	<63 mm (%)	Textural Classification	Munsell Color	Code
13-15A-1		6 (5 and/or 4?)	1.25–1.35	197.2	109.1	1.5	68.8	38.8	88.1	0.8	34.9	19.7	44.7	Silty clayey sand	Dark grayish brown	10YR 4/2
13-15A-2	A.D. 675–900	6	1.45–1.55	171.7	32.6	3.0	9.7	19.9	139.1	1.7	5.6	11.6	81.0	Sandy clayey silt	Grayish brown	10YR 5/2
13-15A-3	900–600 B.C.		3.38–3.48	262.3	11.4	1.2	5.5	4.7	250.9	0.5	2.1	1.8	95.7	Clay	Grayish brown	10YR 5/2
13-13E-4	A.D. 1400–1440	3	1.30–1.40	218.4	149.3	0.6	105.6	43.1	69.1	0.3	48.4	19.7	31.6	Silty sand	Light brownish gray	10YR 6/2

Key: m bs = meters below surface.

Table C-2
Mineralogical Composition of Analyzed Samples from CA-SBA-6896

Sample ID	Elevation (m fd)	Quartz	Feldspars	Biotite	Muscovite	Carbonate Nodules	Root Casts	Shell Fragments
MEC 13-15A-1	1.25–1.35	A	C	VA	VR	C	MC	R
MEC 13-15A-2	1.45–1.55	A	C	VA	VR	A	MC	R
MEC 13-15A-3	3.38–3.48	VA	MC	C	VR	A	C	VR
MEC 13-13E-4	1.30–1.40	A	C	VA	VR	C	MC	R

Key: m fd = meters from datum plane.
Explanation of abundance: VA = very abundant, A = abundant, C = common, MC = moderately common, R = rare, VR = very rare.

Table C-3
Paleontological Composition and Taphonomic Characteristics of Microinvertebrates in Analyzed Samples from CA-RIV-6896

Sample ID	Elevation (m fd)	Bulk Wt. (g)	Fraction Wt. (g)	Ostracodes	Mollusks	Gyrogonites	Taphonomy		
							Fragmentation	Abrasion	Shell Color
MEC 13-15A-1	1.25–1.35	197.2	109.1	2,366	820	0	2	2	Clear
MEC 13-15A-2	1.45–1.55	171.7	32.6	0	7	0	2	2	Clear
MEC 13-15A-3	3.38–3.48	262.3	11.4	0	0	0	—	—	—
MEC 13-13E-4	1.30–1.40	218.4	149.3	2,621	1040	909	2	2	Clear

Key: m fd = meters from datum plane.
*Mollusks and ostracodes were recorded. Ostracodes are the subject of this study; the other groups are only enlisted as major group.

Table C-4
Generalized Environmental Requirements of Ostracode Species Recovered for Site CA-RIV-6896 on the Lake Cahuilla Shoreline, Indio, California

Species	Habitat	Permanence	Temperature		Salinity*	Chemistry*		Paleo/Biogeography**
Cyprinotus glaucus (Furtos, 1933)	Springs, streams, lakes	Permanent	2-32°C	Eurythermic	200–20,000 mg L^{-1}	0.5–80.0 meq L^{-1}	Freshwater to Ca-rich	Across North America
Cypridopsis vidua (O. F. Müller, 1776)	Springs, streams, lakes	Permanent or ephemeral	2-32°C	Eurythermic	100–10,000 mg L^{-1}	0.10–50.0 meq L^{-1}	Freshwater to Ca-rich	Worldwide
Fabaeformiscandona caudata (Kaufmann, 1900)	Lakes, ponds	Permanent	2-32°C	Eurythermic	10–5,000 mg L^{-1}	0.5–10.0 meq L^{-1}	Freshwater to Ca-rich	Cosmopolitan: across North America
Potamocypris smaragdina (Vavra, 1891)	Lakes, ponds	Permanent	2-32°C	Eurythermic	40–3,000 mg L^{-1}	0.20–5.00 meq L^{-1}	Freshwater to Ca-rich	Across North America
Darwinula stevensoni (Brady and Robinson, 1890)	Lakes, ponds	Permanent	2-32°C	Eurythermic	100–2,000 mg L^{-1}	0.10–5.00 meq L^{-1}	Freshwater to Ca-rich	Worldwide

*Forester et al. 2005.
**Anderson et al. (1998), Forester (1991), Külköylüoğlu (2009), Külköylüoğlu and Vinyard (2000).

Table C-5
Total and Relative Abundance of Ostracode Species Recovered from CA-RIV-6896, including Adult/Juvenile (A/J) and Carapace/Valve (C/V) Ratios

						Cyprinotus glaucus				*Cypridopsis vidua*				*Fabaeformiscandona caudata*				*Potamocypris smaragdina*				*Darwinula stevensoni*				
Sample ID	**Elevation (m fd)**	**Bulk Wt. (g)**	**Fraction Wt. (g)**	**Ostracodes**	**Biomass (Ct./g)**	**Ct.**	**%**	**A/J**	**C/V**	**Ct.**	**%**	**A/J**	**C/V**	**Ct.**	**%**	**A/J**	**C/V**	**Ct.**	**%**	**A/J**	**C/V**	**Ct.**	**%**	**A/J**	**C/V**	**Paleosalinity Index**
MEC 13-15A-1	1.25–1.35	197.2	109.1	2,366	12.0	1,578	66.67	0.55	0.01	434	18.33	0.44	0.15	0	—	—	—	339	14.33	0.56	0.14	0	—	—	—	222
MEC 13-15A-2	1.45–1.55	171.7	32.6	0	—	0	—	—	—	0	—	—	—	0	—	—	—	0	—	—	—	0	—	—	—	—
MEC 13-15A-3	3.38–3.48	262.3	11.4	0	—	0	—	—	—	0	—	—	—	0	—	—	—	0	—	—	—	0	—	—	—	—
MEC 13-13E-4	1.30–1.40	218.4	149.3	2,621	12.0	35	1.33	0.00	0.00	1,555	59.33	0.28	0.10	3	1	0	0	935	35.68	0.42	0.09	70	23	1	0	41

Key: m fd = meters from datum plane.

Table C-6
Total and Relative Abundance of Mollusk Species Recovered from CA-RIV-6896, including the Adult/Juvenile (A/J) Ratios

						Physella humerosa			*Physella gyrina aurea*			*Planorbella trivolvis*			*Planorbella* sp. cf. *P. scalaris*			*Valvata* sp. cf. *V. humeralis*		
Sample ID	**Elevation (m fd)**	**Bulk Wt. (g)**	**Fraction Wt. (g)**	**Mollusks**	**Biomass (Ct./g)**	**Ct.**	**%**	**A/J**	**Ct.**	**%**	**A/J**	**Ct.**	**%**	**A/J**	**Ct.**	**%**	**A/J**	**Ct.**	**%**	**A/J**
MEC 13-15A-1	1.25–1.35	197.2	109.1	820	4.16	812	99.04	0.09	0	—	—	8	0.96	1	0	—	—	0	—	—
MEC 13-15A-2	1.45–1.55	171.7	32.6	7	0.04	7	100.00	0.00	0	—	—	0	—	—	0	—	—	0	—	—
MEC 13-15A-3	3.38–3.48	262.3	11.4	0	—	0	—	—	0	—	—	0	—	—	0	—	—	0	—	—
MEC 13-13E-4	1.30–1.40	218.4	149.3	1040	4.76	699	67.23	0.19	288	27.73	0.27	26	2.52	0.33	17	1.68	1.00	9	0.84	1.00

Key: m fd = meters from datum plane.

Table C-7
Generalized Environmental Requirements of Mollusk Species Recovered near Site CA-RIV-6896 at the High-stand Shoreline of Ancient Lake Cahuilla, California

Species	**Family**	**Habitat**	**Permanence**	**Salinity***	**Chemistry (in HCO_3/Ca)***		**Geographic Distribution**
Physella humerosa (Gould, 1855)	Physidae	Streams, lakes, ponds, canals	Permanent or ephemeral	N/A	N/A	Freshwater to Ca- or HCO_3-rich	California, Arizona, Colorado
Physella gyrina aurea (Say, 1821)	Physidae	Streams, lakes, ponds, swamps	Permanent or ephemeral	N/A	N/A	Freshwater	Western North America
Planorbella trivolvis (Say, 1816)	Planorbidae	Weedy species in swamps, ponds, lakes (lentic)	Permanent (oligotrophic environments)	10–800 mg L^{-1}	1–5 mg L^{-1}	Freshwater to Ca- or HCO_3-rich	Across North America
Planorbella scalaris (Jay, 1839)	Planorbidae	Weedy species in swamps, ponds, lakes (lentic)	Permanent (oligotrophic environments)	N/A	N/A	Freshwater	Across North America
Valvata sp. cf. *V. humeralis* (Say, 1829)	Valvatidae	Streams, lakes, ponds (lentic or lotic)	Permanent	50–400 mg L^{-1}	0.1–1.5 mg L^{-1}	Freshwater to HCO_3-rich	Neartic, across northern North America

Calcareous algae (gyrogonites) were restricted to the only sample from MEC 13-13E, where they were very abundant (909)[1] (Tables C-8 and C-9). Tables C-5, C-6, and C-9 show the biomass (number per gram of sediment) and total and relative abundance (frequency in percent) of the microinvertebrate fossil content in the samples.

Table C-8
Generalized Environmental Requirements of Charophyta Species Recovered near Site CA-RIV-6896 at the High-stand Shoreline of Ancient Lake Cahuilla, California

Species	Habitat	Permanence	Temperature	Optimal Seasonality	pH Preference
Chara globularis (Thuillier)	High pH; Ca-rich waters, slow lentic or lotic waters; occasionally in spring seeps; intolerant to high nutrient conditions	Permanent or ephemeral, prefer late spring-summer but may occur year-round	5-25°C; optimum: 17°C-22°C	Mid-January to late September. Peak between late April and mid-July	7.5–10.5; optimum: 9.5–10.5
Chara filiformis (Hertsch)	High pH; Ca-rich waters, slow lentic or lotic waters; occasionally in spring seeps; intolerant to high nutrient conditions	Permanent or ephemeral, prefer late spring-summer but may occur year-round	5-25°C; optimum: 17°C-22°C	Mid-January to late September. Peak between late April and mid-July	7.5–10.5; optimum: 9.5–10.5
Chara canescens (Desv. & Lois)	Brackish or halophytic pools or lagoons; shallow, slow lentic waters (2.5–5.0 m depth); oligotrophic	Permanent or ephemeral, prefer late spring-summer but may occur year-round	5-25°C; optimum: 17°C-22°C	Germination occurs in April and May; spores ripen in the summer (mid-July onwards) may live throughout fall and winter	>8

Source: Andrews et al. 2004; Coletta et al. 2001; Langangen 2000; MarLIN 2013; Pentecost et al. 2006.

Table C-9
Total and Relative Abundance of Calcareous Algae Species Recovered near Site CA-RIV-6896 at the High-stand Shoreline of Ancient Lake Cahuilla, California

Sample ID	Elevation (m fd)	Bulk Wt. (g)	Fraction Wt. (g)	Gyrogonites (Ct.)	Biomass (Ct./g)	*Chara globularis*		*Chara filiformis*		*Chara canescens*	
						Ct.	%	Ct.	%	Ct.	%
MEC13-15A-1	1.25–1.35	197.2	109.1	0	—	0	—	0	—	0	—
MEC13-15A-2	1.45–1.55	171.7	32.6	0	—	0	—	0	—	0	—
MEC13-15A-3	3.38–3.48	262.3	11.4	0	—	0	—	0	—	0	—
MEC13-13E-4	1.30–1.40	218.4	149.3	909	4.2	472	51.9	323	35.6	79	8.7

Key: m fd = meters from datum plane.

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[1] Abundance explanation (number of individuals): Extremely abundant (>1001), very abundant (>501<1000), abundant (>101<500), moderately abundant (>51<100), common (>21<50), rare (>6<20), and extremely rare (<5).

Based on Delorme (1969, 1989), standard taphonomic parameters, such as fragmentation, abrasion, disarticulation (carapace/valve [C/V] ratios), and adulthood (adult/juvenile [A/J] ratios) were recorded to establish the synecology (ecology of the communities) as opposed to the autoecology (ecology of single species) of the ecosystem (Adams et al. 2002). Fragmentation is the degree of breakage shown by the shells; abrasion is the degree of scratching of the shell surface. Disarticulation applies to bivalves only and indicates if the two valves are attached or separated. The taphonomic parameters were used to recognize degrees of transport and/or burial characteristics such as desiccation and sediment compaction. The rates of fragmentation, abrasion, and disarticulation are realistic indicators of transport; commonly these parameters show more damage with increasing transport. One must be cautious in using this criterion, but the nature of the deposits suggests that microinvertebrates may reflect the lake's hydraulic properties. Other features such as encrustation and coating were used to determine authigenic mineralization or stream action, respectively. Corrosion was used as an indicator of diagenetic effects over time. The redox index and color of valves reflected burial conditions. The A/J and C/V ratios were used as indicators of biocenosis, that is, if a living, local population established on site (Palacios-Fest et al. 2001; Whatley 1983).

RESULTS

Sedimentary Record

Table C-1 and Figure C-1, respectively, show the textural classification and particle-size diagrams of the four samples studied. The three samples from MEC 13-15A consist of dark grayish brown (10YR 4/2; moist) to grayish brown (10YR 5/2; moist) organic-rich silty clayey sand to clay (Table C-1). The mineral composition is dominated by biotite, quartz, feldspars, and carbonate nodules, with minor amounts of root casts, muscovite, and mollusk and ostracode fragments (Table C-2). Sample MEC 13-15A-1, the uppermost sample from MEC 13-15A, was fossiliferous, while the other two deeper samples from this MEC contained extremely rare mollusks or were unfossiliferous (Table C-3). Figure C-1a shows variable water discharge as indicated by the particle-size diagram. The bottom sample (MEC 13-15A-3) appears to be a desiccation surface deprived of living forms; the abundant carbonate nodules support this interpretation. Sample MEC 13-15A-2 shows a slight increase in the sand fraction, probably related to stream flow or eolian deposition, whereas the uppermost sample (MEC 13-15A-1) indicates a steady stream flow that introduced and permitted to settle a large assemblage of ostracodes and mollusks, as discussed below.

One sample was analyzed from MEC 13-13E, located 360 m northwest of MEC 13-15A (see Chapter 9). Sample MEC 13-13E-4 is composed of light brownish gray (10YR 6/2, moist) silty sand (Table C-1) with a similar mineralogical composition to the samples from MEC 13-15A (Table C-2). The particle-size distribution is dominated by medium sand and silt, similar to the uppermost sample analyzed from MEC 13-15A and indicating moderately high energy entering the system; however, if the origin of sediments is eolian, then one must consider the possibility that these sediments were accumulating in an existing pond or wetland environment where mollusks and ostracodes were already living (Figure C-1b). Both samples MEC 13-13E-4 and MEC 13-15A-1 contain a diverse and abundant biological assemblage including ostracodes, mollusks, and calcareous algae, as described in "Biological Record," below.

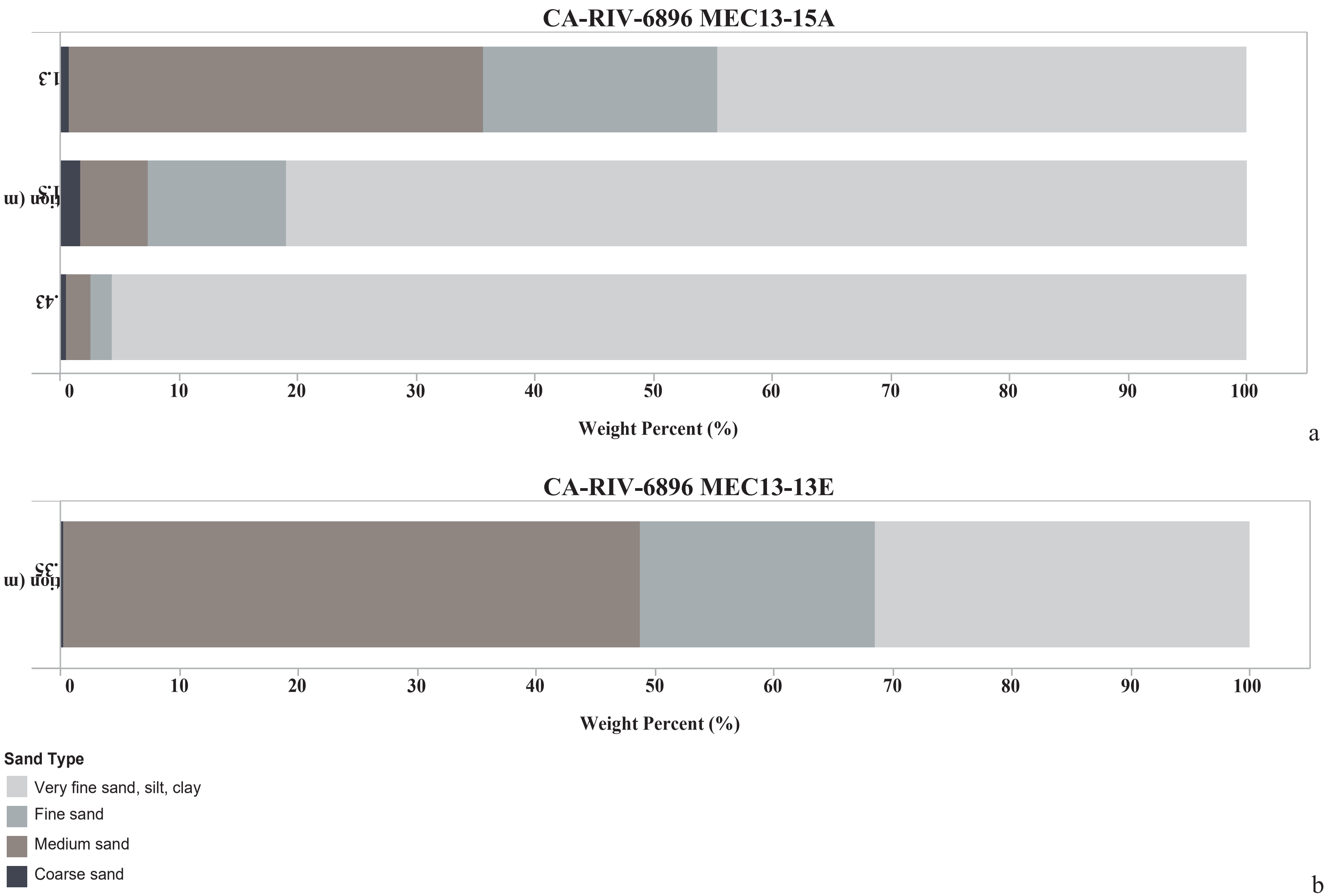

Figure C-1 Particle-size analysis of: (a) MEC 13-15A; and (b) MEC 13-13E. Particle-size analysis is described in the text.

Biological Record

Table C-3 summarizes the biological contents of Lake Cahuilla samples and the overall taphonomic characteristics recorded. Ostracodes, mollusks, and calcareous algae were present. Five ostracode species were identified: *Cyprinotus glaucus* (Furtos, 1933), *Cypridopsis vidua* (O. F. Muller, 1776), *Fabaeformiscandona caudata* (Kaufmann, 1900), *Potamocypris smaragdina* (Vavra, 1891), and *Darwinula stevensoni* (Brady and Robinson, 1890). Table C-4 shows the ecological requirements of the ostracode species identified in this study. Table C-5 displays the total and relative abundance by species as well as the adulthood and disarticulation ratios.

Mollusks were equally diverse (five species), including the snails *Physella humerosa* (Gould, 1855), *Physella gyrina aurea* (Say, 1821), *Planorbella trivolvis* (Say, 1816), *Planorbella* sp. cf. *P. scalaris* (Jay, 1839), and *Valvata* sp. cf. *V. humeralis* (Say, 1829). Table C-7 shows the ecological requirements of the mollusk species identified in this study.

Gyrogonites of Charales occurred only in sample MEC 13-13E-4, in which three *Chara* species were represented: *C. globularis* (the most abundant), *C. filiformis*, and *C. canescens* (the rarest). As shown in Table C-8, these three species tolerate a wide range of conditions and appear to prefer high pH. However, the occurrence of *C. canescens* may be associated with its greater tolerance to high salinity (up to 3.4 percent; Langangen 2000).

Based upon the ostracode composition, a paleosalinity index was developed (Table C-5). The qualitative paleosalinity index takes into consideration the salinity tolerance of the species present in the area based on our current knowledge of their ecological requirements presented in the North American Nonmarine Ostracodes Database (NANODe) website (Forester et al. 2005) and other references (Curry 1999; Palacios-Fest 1994). The equation used for the present study is:

$$\mathbf{SI} = [3(\%\ \textit{Cyprinotus glaucus}) + 2(\%\ \textit{Cypridopsis vidua}) + (\%\ \textit{Fabaeformiscandona caudata})] - [(\%\ \textit{Potamocypris smaragdina}) + 2(\%\ \textit{Darwinula stevensoni})]$$

The index positively weighs species with incrementally higher salinity tolerances and negatively weighs species with incrementally lower salinity tolerances. In spite of the fragmented record, the paleosalinity index shows a predominance of saline conditions throughout the area's environmental history (see "Interpretations" and "Discussion," below).

Continental ostracodes and mollusks inhabit waters of different hydrochemical composition, but at the species level many are very sensitive to water chemistry. Ostracode and mollusk assemblages can be used to recognize the three major water types defined by Eugster and Hardie (1978).

- **Type I:** Ca^{2+}, Mg^{2+}, and HCO_3^- -dominated water; typically freshwater or very low salinity conditions.
- **Type II:** Ca^{2+} -enriched/HCO_3^- - depleted water; additionally containing the combinations of Na^+, Mg^{2+}, SO_4^{2-}, or Na^+, Mg^{2+}, Cl^-; ranges from low salinity to hypersaline conditions.

- **Type III:** Ca^{2+} -depleted/$HCO_3^- + CO_3^{2-}$ (alkaline)-enriched water; usually containing combinations of Na^+, Mg^{2+}, Cl^-, or Na^+, Mg^{2+}, SO_4^{2-}; ranges from low salinity to hypersaline conditions.

This spectrum clearly shows that water chemistry plays a major role in the geographic distribution of microinvertebrates. In addition to water chemistry, temperature is another factor that affects the distribution of these organisms, as their latitudinal distribution demonstrates. Many ostracode species respond to temperature through both reproductive and survival ability (De Deckker and Forester 1988; Delorme and Zoltai 1984; Forester 1987). For example, *Cytherissa lacustris* is limited to water temperatures lower than 23°C and is common in subpolar regions, whereas *Limnocythere bradburyi* is restricted to warm temperatures of low to midlatitudes (Delorme 1978; Forester 1985). Their sensitivity to temperature makes ostracodes very useful for paleoclimate reconstructions (Cohen et al. 2000; Palacios-Fest 2002). Once the ecological requirements of ostracodes are determined, it is possible to reconstruct paleoenvironments from the geologic record (Delorme 1969; Holmes and Chivas 2002; Palacios-Fest 1994). Similarly, Sharpe (2002, 2003) has documented some of the ecological preferences of several mollusk species in western North America. The mollusk record was used to integrate the following paleoenvironmental reconstruction.

INTERPRETATIONS

The combined information of ostracodes, mollusks, and gyrogonites provides solid evidence for the environmental conditions that prevailed in the area of study.

Geomorphic and chronometric findings (see Appendix B) suggest that the strata yielding microinvertebrates at MEC 13-15A (Samples 1 and 2) and MEC 13-13E (Sample 4) are not synchronous. The composition of the faunal assemblages from each of the two contexts is distinct, corroborating this interpretation.

In MEC 13-13E (Sample 4), the faunal composition is relatively diverse and abundant including ostracodes, mollusks, and calcareous algae gyrogonites. The lacustrine deposits represented by Sample 4 likely accumulated during Lacustrine Intervals 3–2 (circa A.D. 1395–1460 and A.D. 1505–1600; Philibosian et al. 2011) (see Appendix B:Table B.3). Gyrogonites of calcareous algae are also diverse and abundant in Sample 4, represented by *Chara globularis*, *C. filiformis*, and *C. canescens* (Figure C-3). Ostracodes were the most diverse, including *Cypridopsis vidua*, *Potamocypris smaragdina*, and a few specimens of *Darwinula stevensoni*, *Cyprinotus glaucus*, and *Fabaeformiscandona caudata*. Mollusks were similarly abundant and diverse with significant concentrations of *Physella humerosa*, *P. gyrina aurea*, *Planorbella trivolvis*, *Planorbella* sp. cf. *P. scalaris* along with scarce *Valvata* sp. cf. *V. humeralis*. This assemblage suggests that slow flow or standing water favored calcareous algae to colonize the environment first; then microinvertebrates settled to create a biocenosis. The biological associations imply alkaline freshwater conditions under which the ostracodes, mollusks, and calcareous algae established a biocenosis.

In contrast, the faunal composition of Samples 1 and 2 at MEC 13-15A shows less diversity, and calcareous algae gyrogonites are absent (Tables C-3, C-5, and C-6; Figure C-2). According to Onken (Appendix B), these two samples likely correlate to the Lacustrine Intervals 6–5 (circa A.D. 855–910 and A.D. 955–1040) of Philibosian et al. (2011). The significant biological

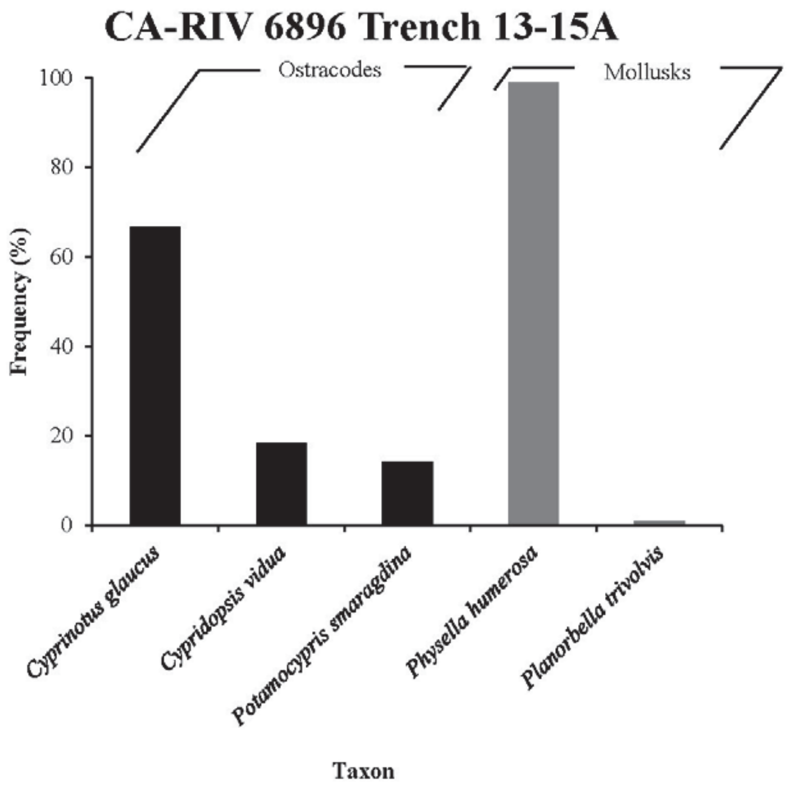

Figure C-2 Biological relative abundance of ostracodesand mollusks, at MEC 13-15A.

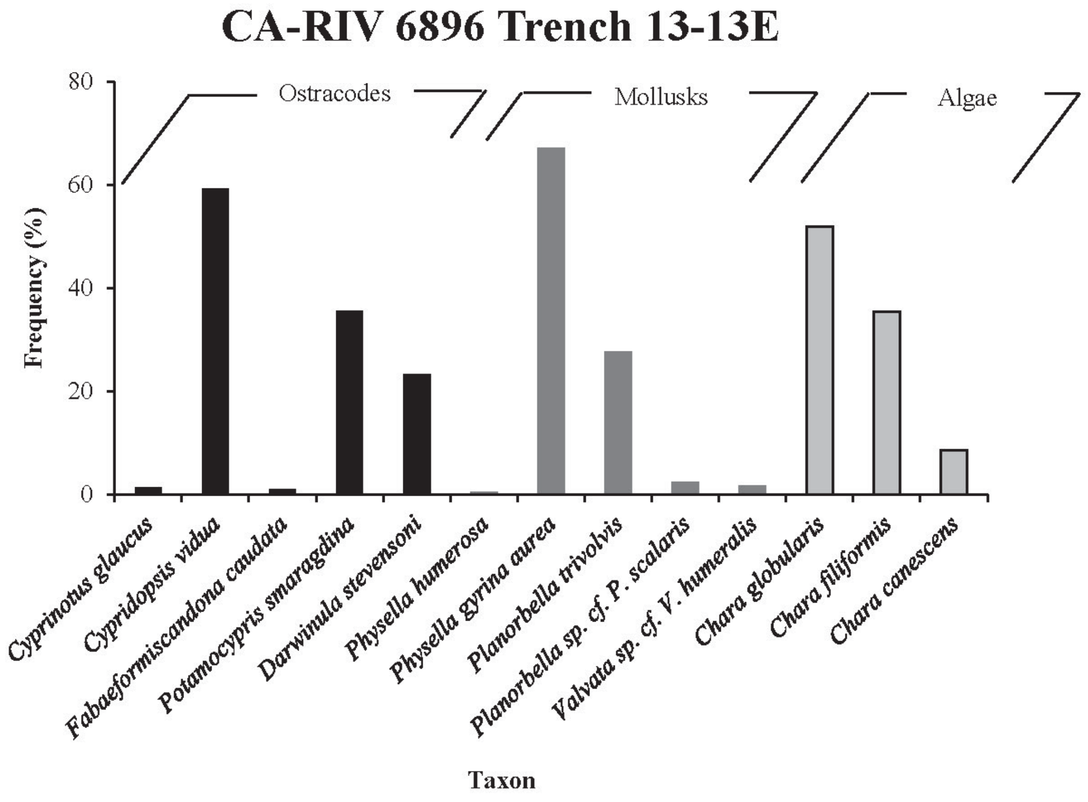

Figure C-3 Biological relative abundance of ostracodes mollusks and gyrogonites at MEC13-13E.

differences between the upper two samples from MEC 13-15A and the sample from MEC 13-13E suggest the strata are not contemporary, implying that the two strata represent different lacustrine intervals and different water chemistry conditions (Figures C-2 and C-3).

The ostracode assemblage found in the uppermost MEC 13-15A lacustrine stratum (Sample 1) suggests fresh to moderately saline water conditions derived from the 1:2 ratio of ostracode species *Cyprinotus glaucus*, *C. vidua* and, to a lesser extent, *Potamocypris smaragdina* (Figure C-2). These three species established a biocenosis as demonstrated by the 1:2 or 1:3 adulthood ratios and good preservation, consistent with autochthonous populations. As shown in Table C-4, all species in this sample tolerate a salinity range between 200 and 3,000 mg/L TDS supporting this interpretation. In marked contrast to the MEC 13-13E sample, mollusks at MEC 13-15A are virtually mono-specific, represented by *Physella humerosa* (abundant) and a single shell fragment of *Planorbella trivolvis* (Figure C-2). Although the *P. trivolvis* specimen could have been reworked from the shoreline, *Physella humerosa* provides mixed signals because the adulthood ratio (0.09) implies that juveniles were transported to this location but failed to establish a biocenosis. However, this seems inconsistent with the low fragmentation and abrasion rates (<2%) suggesting in situ development of a community.

As discussed above, the biological composition of the fossiliferous samples from MECs 13-15A and 13-13E are distinctly different. It is assumed that MEC 13-13E characterizes long-term stability permitting invertebrates and algae to grow. The more organic-rich sample MEC 13-15A-1 contains no gyrogonites and almost mono-specific mollusks associated with a fresh to moderately saline ostracode assemblage. The salinity-tolerant *Cyprinotus glaucus* is most abundant in this stratum and is accompanied by two other saline species: *C. vidua* and *Potamocypris smaragdina*. Eventually, the environment evolved to saline and alkaline conditions adverse to calcareous algae. Onken (Appendix B) elegantly summarizes my interpretation when she identifies that the short-lived lake stands did not completely dry out but left enough water to sustain a small *C. glaucus* population until the Colorado River shifted again, quickly refilling the Salton Trough and allowing this species to immediately flourish in the newly expanded freshwater environment.

The deepest sample from MEC 13-15A (Sample 3) represents an earlier high stand that might be correlative with one of the circa 400 B.C. high stands identified by Waters (1983). The unit is unfossiliferous and appears to be a deflation surface. Eolian sands accumulated on top of this unit until the Colorado River diverted into the Salton Trough Basin during a subsequent high stand. The lack of fossils may indicate that the lake water was hypersaline. Alternatively, the absence of fossils might be the result of the very fine texture of the lakebed sediments comprising this sample because fines can clog gills, setae, and other sensitive physiological structures, making it difficult for invertebrates to survive in environments dominated with very fine substrates.

The sedimentary and stratigraphic record suggests that in most cases eolian sediments filled this part of the Lake Cahuilla basin, implying that invertebrates and algae arrived by means of external sources such as waterfowl. According to Onken (personal communication February 10, 2014), no evidence of a spring or fluvial discharge was found in the field, leaving the external sources as the main mechanisms introducing microinvertebrates into the lake.

DISCUSSION

The microinvertebrate and gyrogonite records from late Holocene Lake Cahuilla provide fragmentary evidence of an ever-changing Salton Trough. The limited data offer the unique opportunity to understand some characteristics of aquatic life at times when the Colorado River diverted into the Salton Trough, events that occurred at least six times during the past 1,200 years (Moratto 2011; Philibosian et al. 2011). These inundation cycles are a refinement of Waters' (1983) and Wilke's (1978) attempts to reconstruct the hydrologic history of Lake Cahuilla. Neither attempt, however, dealt with biological evidence to reconstruct the lake's paleoecology. Stearns (1902) acknowledged the great abundance of this species (referring also to the abundance of *Tryonia protea*; not identified in this study) stating that "there is probably no area of equal extent on the face of the earth with such an immense number of shells of the genera above mentioned" (Walker 1961). Surprisingly, no evidence of mussels (*Anodonta dejecta*) was recorded in CA-RIV-6896 profiles (although *A. dejecta* shell fragments are found in archaeological deposits at the site; see Appendix Q), suggesting that the very fine sediments in still water conditions prevented this group from settling. Bowersox (2003) estimated the history of salinization of Lake Cahuilla around A.D. 1500 that compares well with the estimated A.D. 1400–1440 span of Lacustrine Interval 3, that is, during the Medieval Climatic Anomaly (MCA).

Data in this investigation indicate freshwater conditions at the time of deposition of the analyzed fossil-bearing lacustrine sediments from MECs 13-15A and 13-13E. Contexts with greater diversity and abundance of microinvertebrates and gyrogonites are interpreted as reflecting more optimal (less saline) conditions. The occurrence of calcareous algae reflects the alkaline characteristics of Lake Cahuilla. The elevations of the lacustrine strata analyzed imply that they represent high-stand or near high-stand conditions. To identify the progressive salinization as lake levels declined suggested by Bowersox (2003), it would be necessary to identify other fossiliferous stratigraphic intervals containing ostracodes and mollusks. The occurrence of calcareous algae sustains the alkaline characteristics of Lake Cahuilla as well.

To understand the significance of the species present in the area it is important to consider their modern ecology. All species are eurytopic, that is, today they live in lakes with a wide chemical, thermal, and hydroclimatic spectrum (Bradbury and Forester 2002; Delorme 1989; Forester 1986, 1987, 1991; Forester et al. 2005; Forester et al. 1994; Smith and Forester 1994). Occurrence and dominance of *Cyprinotus glaucus* in MEC 13-13E indicate that Lake Cahuilla was a fresh to moderately saline environment during Lake Intervals 3–2 of Philibosian et al. (2011). This interpretation is consistent with Bowersox's (2003) interpretation stating "paleosalinity was 0.7 ppt (0.07%) at high stand, increased slowly to 6 ppt (0.6%) at -55 m (55 m below highstand), then increased rapidly to >35 ppt (3.5%) at -85 m (modern Salton Sea surface level)." For reference, the average salinity of seawater is 3.5 percent.

Amongt mollusks, to the best of my knowledge, the ecological requirements of *Physella humerosa*, *P. gyrina aurea* (Physidae) and *Planorbella* sp. cf. *P. scalaris* (Planorbidae) are not well understood. The genera *Physella* and *Planorbella* are worldwide inland-waters gastropods with a wide range of tolerance to salinity and hydrochemical conditions. *Planorbella trivolvis* and *Valvata* cf. sp. *V. humeralis*, by contrast, are known to live in restricted (stenotopic) hydrochemical environments (usually low range), implying that their occurrence in site CA-RIV-6896 reflects freshwater settings (Table C-7).

Modern calcareous algae prefer alkaline lentic or lotic waters as indicated in Table C-8. The three species found in CA-RIV-6896 (*Chara globularis*, *C. filiformis*, and *C. canescens*) are consistent with these requirements. *C. canescens* may have appeared as the salinity and alkalinity of the lake increased. The eurytopic characteristics of the species limit elaborating on its paleoecological implications in this study.

Diatoms or Bacillariophyta are a major group of algae characterized by a frustule made by two valves to protect the single-cell individual. They can live as independent cells or form colonies in the shape of filaments or ribbons (e.g., Fragilaria), fans (e.g., Meridion), or stars (e.g., Asterionella). Diatoms are marine and nonmarine benthic (bottom dwellers) or planktonic (floating forms) and host a variety of forms. The group evolved to elaborate silica walls that reflect the types of habitat to which the particular species is adapted. Nearly all diatoms are microscopic, ranging in size from 2 to 500 µm. Sensitive to water chemistry, diatoms are valuable tools for identifying recent and fossil environments. Many species have distinct ranges of pH and salinity, as well as other parameters (e.g., nutrient concentration, suspended sediment, flow regime, elevation, and different type of anthropogenic disturbance (Stoermer and Smol 1999). In the geologic record, the fossilized silica frustules are the only remains of diatoms that may be used to reconstruct past environments. Low-energy environments favor preservation.

Frequently, diatoms occur in carbonate environments, although they do better in silica-rich waters. Several species colonize and form biocenosis in extreme conditions; these are known as extremophiles. For example, David Patterson 2007) identified some species in Mono Lake, whereas Lange and Tiffany (2002) found a diverse microflora in the Salton Sea. Diatoms are a common element in harsh environments like Lake Cahuilla and might provide a unique opportunity to investigate the presence and diversity of this useful paleoecological indicator in future investigations.

CONCLUSIONS

1. Site CA-RIV-6896 offered a unique opportunity to analyze the biological composition of Lake Cahuilla’s Lacustrine Intervals 6–5 and 3–2.

2. For the first time, a semidetailed micropaleontological analysis permitted the environmental reconstruction of ephemeral Lake Cahuilla.

3. The significant paleoenvironmental differences between the uppermost lacustrine deposits at MECs 13-15A and 13-13E suggest that they are not contemporaneous.

4. In light of the data from site CA-RIV-6896, microinvertebrates and calcareous algae indicate that Lake Cahuilla offered prehistoric inhabitants brief windows of freshwater conditions between 400 B.C. and A.D. 1600.

5. Further micropaleontological and geochronological control would be necessary to generate a better paleoclimate history of ancient Lake Cahuilla.

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