Paleoenvironmental Reconstruction of Human Activity in Central Arizona Using Shell Chemistry of Hohokam Canal Ostracodes*

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The prehistoric Hohokam are the only known culture to develop large-scale irrigation systems before the arrival of Europeans to the United States. Hohokam social evolution was based, in part, on intensive agriculture. To date, most models of Hohokam irrigation agriculture (i.e., hydrologic and sedimentologic models) fail to address dynamics like flow regime, seasonality, canal use and abandonment (Henderson and Hackbarth, 1939). Biota recovered from Hohokam canals often include ostracodes, carbonate-secreting microcrustaceans that are sensitive to hydrochemical changes. $^{m}(Mg/Ca)_{v}$ and $^{m}(Sr/Ca)_{v}$ ratios in the ostracode *Limnocythere staplini* can be converted into approximate temperature and salinity values at the time of calcification. Ostracode shell chemistry is becoming a powerful tool for understanding the history of canal water chemistry, intensity of land use, and human impact on soil. This study uses multiple regression models to generate the first paleoenvironmental estimates of temperature and salinity from ostracode shell chemistry. Temperature estimates suggest that most canals were used between late winter (February–March) and the premonsoonal season (May–June). Salinity estimates apparently vary over time. Both paleoenvironmental estimates are in good agreement with historic records for the Phoenix area. © 1997 John Wiley & Sons, Inc.

INTRODUCTION

In 1994, Palacios-Fest (1994a) presented the first attempt to use ostracode shell chemistry to reconstruct ancient Hohokam canal environments. At the time, the results were consistent with paleoecologic data, although experimental regression models to convert shell chemistry ratios into temperature

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* *NOTE TO THE READER:* In 1994, I prematurely published some results on ostracode shell chemistry from Hohokam irrigation canals at Las Acequias, Tempe, Arizona (Palacios-Fest, 1994a). Later, I developed an experimentally-derived regression model to convert trace element values into empirical temperature and salinity estimates for *Limnocythere staplini*. The current note documents the latest findings and interpretation of my preliminary results using this statistical model. *Limnocythere staplini* shell chemistry provides a resourceful method to reconstruct the Hohokam canals' history between A.D. 700 and A.D. 1450. To avoid unnecessary duplication, the reader is encouraged to take a look at the original publication for background research and locality description.

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and salinity estimates were not yet available. The present study is an *addendum* to that earlier paper and will focus on the geochemical data and interpretation. The purpose of this study is to analyze the behavior of trace elements (Mg^{2+} and Sr^{2+}) in *Limnocythere staplini* as a tool for understanding canal water chemistry, intensity of land use, and human impacts to soil. By using this technique it may be possible to identify key climatic factors which affected the operation of Hohokam canals and isolate them from human factors (Henderson & Hackbarth, 1993).

Continental ostracodes are sensitive to differences in water chemistry at the species level. Strong evidence suggests that these organisms selectively occur in either one of Eugster and Hardie's (1978) three major water pathways in continental waters (Forester, 1983, 1986; Palacios-Fest, 1994a). Ostracode hydrochemical requirements have been previously determined by numerous authors in an attempt to establish the (paleo)ecologic response of these creatures to the environment (Delorme, 1969, 1971, 1989; Turpen and Angell, 1971; Cadot and Kaesler, 1977; Bodergat, 1983; Bodergat et al., 1995).

The pioneering work of Chivas et al. (1983) was the first to propose using trace elements to calcium molar ratios from ostracode valves for paleoenvironmental reconstructions. They suggested that it is possible to establish an environmental correlation between shell chemistry and temperature and salinity to reconstruct the history of ancient water bodies. Subsequent work by this author and his team (Chivas et al., 1986a, 1986b, 1993) have demonstrated the potential of this strategy. Other attempts to use ostracode shell chemistry have produced significant, although controversial results, suggesting that the $^{m}(Mg/Ca)_{v}$ ratio in the shell may respond to salinity and not to temperature and Mg content in the water (Engstrom and Nelson, 1991). Palacios-Fest (1994b) proposed an alternative strategy to calculate temperature and salinity from the Mg/Ca and Sr/Ca molar ratios from ostracode valves, respectively. In contrast to previous studies, Palacios-Fest suggested that Mg^{2+} may be directly correlated to temperature and Sr^{2+} to the total dissolved solids of the water. By using a multiple regression model with an interactive term for temperature he argues that it is possible to calculate those parameters from the geologic record of lakes and other continental water bodies. These regression models are applied in this study to establish the hydroclimatic signature of the prehistoric Hohokam canals and the historic Peterson Ditch in the vicinity of the Tempe Outer Loop in the Phoenix Basin.

Palacios-Fest (1994a) summarized the history of research along the Phoenix Basin Hohokam Canals. The archaeomagnetic dates yielded ages ranging from A.D. 700 to 1450 (Henderson, 1989). At Las Acequias four Hohokam Cultural Periods (Pioneer, Colonial, Sedentary, Classic) were recognized. Additionally, a historic record derived from the Peterson Ditch, a canal used by Anglo inhabitants of this region late in the last century (between 1885 and 1892), was available (Palacios-Fest, 1994a). Thirty-seven canals conformed the Las Acequias irrigation system, ranging in length from 1 to 25 km and were classified as main (fed by the Salt River), distributary (fed by main canals), and lateral or field canals (to flood agricultural areas).

MATERIAL AND METHODS

Palacios-Fest (1994a) described sampling and laboratory procedures used in this study. Nineteen of the 30 samples analyzed were fossiliferous. *Limnocythere staplini,* the most abundant species, was selected for shell chemistry analysis. One hundred twenty-five individual valves were recovered for this study. Between three and ten specimens were selected from each sample. Valves were thoroughly cleaned by immersing them in a 5% H_2O_2 at room temperature for 30 min to remove any organic matter and sediments that were adhering to them. A fine brush (000) was used to mechanically remove extraneous particles while valves were immersed in this solution. Then, the valves were rinsed four times in 18 MΩ water and cleanliness was verified under the microscope. Valves were weighed in a Cahn 29 electronic balance (with weighing precision of 0.1 μg and accuracy of $\pm$0.002 μg), and dissolved in 3 ml of a 2% (0.12N) HCl distilled solution (prepared in the Isotope and Trace Element Geochemistry Laboratory of the Department of Geosciences, University of Arizona).

Trace element analysis of Mg^{2+} and Sr^{2+} was conducted using a VG-TN7200 inductively coupled plasma mass spectrometer (ICP-MS). Detection limits for Mg^{2+} and Sr^{2+} were 0.1 ppb; 2σ above background. All analyses were run against multielement standards prepared from Spex™ stock solutions. In order to obtain enough counts for good counting statistics, four scans were made per sample, with four passes per scan (a process which consumed at least 2 ml of solution). Because of the instrument's sensitivity to major ions like calcium, its content in ostracode valves were determined stoichiometrically. Spectrometric data were grouped by sample and archaeomagnetic age to generate a trace element chronology.

Experimentally derived multiple regression models obtained from *Limnocythere staplini* by Palacios-Fest (1994b, in press) yielded standard coefficients that are applied in this investigation to calibrate their potential application to Hohokam prehistoric records. The multiple regression model is expressed by

$$^{m}(\mathrm{Te/Ca})_{\mathrm{valve}} = \beta_0 + \beta_1 \times \mathrm{TDS} + \beta_2 \times \mathrm{T}\,(^\circ\mathrm{C}) \qquad (1)$$

where Te is either Mg or Sr, β_0 is the constant, β_1 is the coefficient for salinity, and β_2 is the coefficient for the interactive term for temperature. Thus the best fitting model for temperature takes the form of

$$\mathrm{T}\,(^\circ\mathrm{C}) = \frac{^{m}(\mathrm{Mg/Ca})_{\mathrm{valve}} - \beta_0 - \beta_1 \times \mathrm{TDS}}{\beta_2} \qquad (2)$$

where $\beta_0 = -0.00083$, $\beta_2 = 0.00074$ is significantly different from zero ($p < 0.001$), but $\beta_1 = 2 \times 10^{-7}$ is not significantly different from zero ($p > 0.05$). As expected from previous studies of continental ostracodes, the $^{m}(Mg/Ca)_v$ ratios of *L. staplini* in the Hohokam canals illustrate the temperature dependence of Mg uptake (Chivas et al., 1983, 1986a, 1986b; Engstrom and Nelson, 1991). In contrast to those studies, the regression models used in this work demonstrate that temperature may be inferred independently of the water Mg/Ca molar ratios. This experimental approach appears to provide a useful technique to elaborate high-resolution studies of ancient water bodies.

Similarly, the best fitting model for salinity takes the form of

$$\mathrm{TDS} = \frac{^{m}(\mathrm{Sr/Ca})_{\mathrm{valve}} - \beta_0 - \beta_2 \times \mathrm{T}\,(^{\circ}\mathrm{C})}{\beta_1} \tag{3}$$

where $\beta_0 = 7 \times 10^{-5}$, $\beta_1 = 2 \times 10^{-7}$ is significantly different from zero ($p < 0.001$), but $\beta_2 = 7 \times 10^{-5}$ is not significantly different from zero ($p > 0.05$). Once again, as expected from previous studies the $^{m}(Sr/Ca)_v$ ratios of *L. staplini* in these canals responded to the Sr concentration in the water (Chivas et al., 1983, 1986a, 1986b; Engstrom and Nelson, 1991), but more significantly to the total dissolved solids, thus through Eq. (3) it is possible to empirically estimate salinity. Figure 1 shows preliminary calibrations of experimental coefficients with modern ostracodes (*Limnocythere staplini* and *Limnocythere ceriotuberosa*) from several lakes in Utah; they yielded a close correlation between measured and empirically estimated parameters by means of these equations (Palacios-Fest, in press).

RESULTS

Paleohydrochemical Data

Figure 2 and Table I summarize *Limnocythere staplini* shell chemistry, inferred temperature and salinity records, and t-test analysis of Las Acequias canals during prehistoric Hohokam and historic operation. Well-defined covariant trends of Mg/Ca and Sr/Ca molar ratios are evident throughout the canals' history, suggesting that temperature and salinity covaried during canal operations probably due to evapotranspiration with increasing temperature (a trend proposed by De Deckker and Forester, 1988). The apparent low values of $^{m}(Mg/Ca)_v$ and $^{m}(Sr/Ca)_v$ observed in these valves is consistent with values recorded elsewhere for other species (Engstrom and Nelson, 1991). To verify the statistical validity of the data, a t-test analysis for related samples of the empirically estimated parameters (temperature and salinity) was conducted. The t-tests are indeed statistically significant ($p < 0.05$) for both temperature and salinity. Measures of association also indicate a moderate to appreciable correlation with each one of the trace element ratios ($r_m > 0.45$ for temperature; >0.70 for salinity).

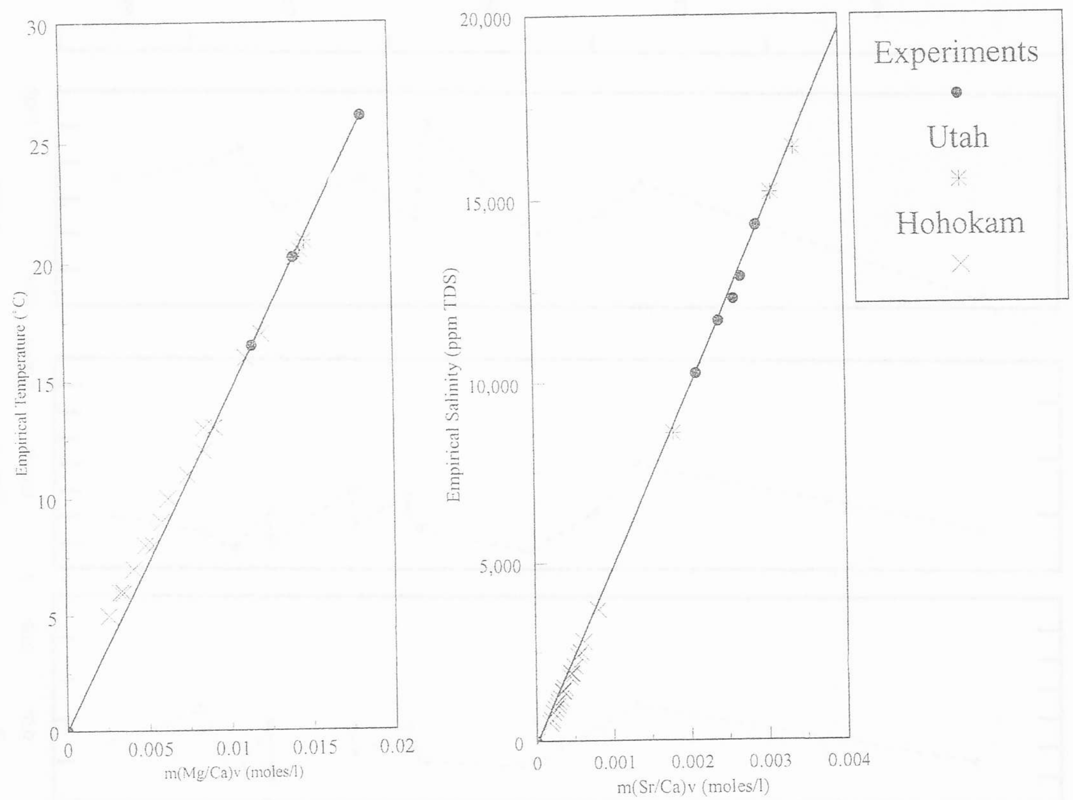

Figure 1. Comparison of the empirical temperature and salinity estimates from experimental data, modern living populations and Hohokam canal populations using multiple regression models (Palacios-Fest, 1994, in press): (a) empirical temperatures against $^{m}(Mg/Ca)_v$ values and (b) empirical salinity against $^{m}(Sr/Ca)_v$ values. Symbols: (●) experimental data; (*) calibration with Utah natural populations; and (×) Hohokam ostracodes data. (Modified from Palacios-Fest, in press.)

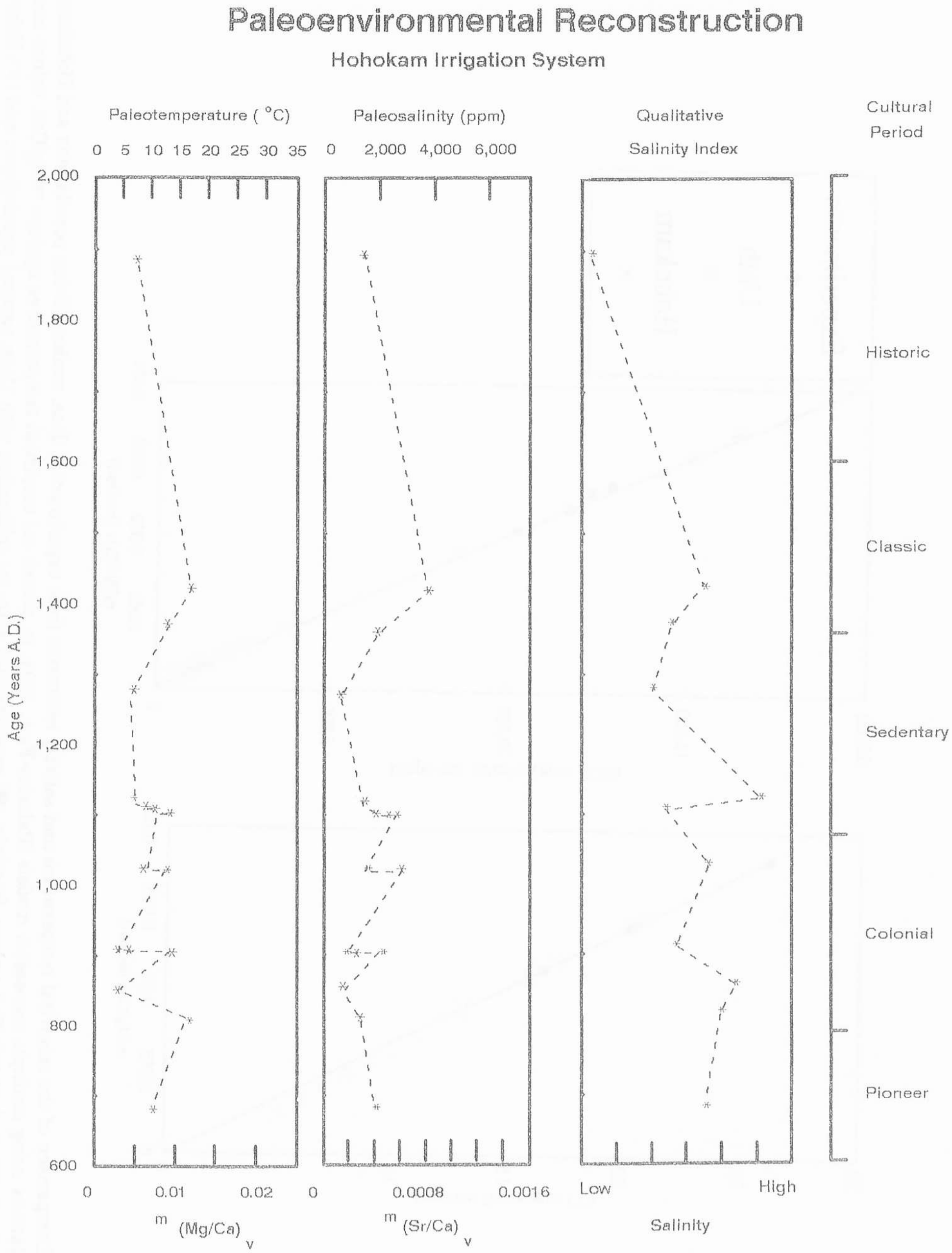

Figure 2. Trace element paleoenvironmental reconstruction of Hohokam canals history based upon values shown in Table I. The trace element records are compared with the paleosalinity index generated from ostracode relative abundance. Note the good correlation between the geochemical and paleoecological trends (modified from Palacios-Fest, 1994a; see original paper for details).

The Mg/Ca ratios from *L. staplini* recorded temperature ranges that are low in comparison with annual averages for the Phoenix Basin, but reasonable if most of the canal discharge was occurring in the spring. There is good agreement between these estimates and late winter-spring (late February–early June) average minimum to mean air temperature records for Phoenix (6–21°C) by the National Climatic Data Center (1876–1995). These low values suggest that ostracodes, as most other crustaceans, molt their skeletons between midnight and dawn, 12 a.m. to 7 a.m. (Martha Palacios-Fest, personal communication, 1994; Secretaria de Pesca, Mexico). Because most canals are very shallow (<60 cm deep), it is reasonable to assume that canal water temperatures reflect those of the air in the early hours in the Phoenix Basin during the prehistoric Hohokam era. To support this hypothesis, Figure 3 shows how the empirical temperatures behave with respect to the summary of the monthly climatological data from 1876 to 1995 obtained from the National Climatic Data Center (1876–1995).

The Sr/Ca ratios from *L. staplini* also indicated salinity values (TDS as ppm) that are in good agreement with salinity measured early this century for the Salt River at Tempe, Arizona (800–1200 ppm) (Ackerly, 1989), source of the Peterson Ditch (the Anglo canals). Water diverted from the Salt River to the irrigation system contained moderate levels of dissolved solids, but there are pronounced seasonal and annual variations in the river's salt content (Ackerly, 1989). Ackerly (1989) suggests that salinity increases downstream in the Salt River, towards the ends of the canals. With the use of Sr/Ca ratios and salinity coefficients developed by Palacios-Fest (1994b, in press) it is possible to obtain reliable estimates of salinity from prehistoric canals. The empirical temperature and salinity estimates from the Hohokam canals show a significant correlation with the experimental data (Figure 1).

The temporal boundaries between the four Hohokam cultural intervals are shown on the trace element diagram (Figure 2). During the Early Pioneer Period (pre A.D. 700; samples F-567 and F-573), trace elements indicate that water temperature was variable (8 ± 1 to 13 ± 4°C) while water was moderately saline (1100 ± 500 to 2400 ± 1200 ppm). Trace element geochemistry suggests that canal hydrochemical compositions became diluted during the Colonial Period (A.D. 700–910; samples F-742 and S-924), with salinity values between 600 ± 200 and 1200 ± 500 ppm. Temperatures dropped to about 5 ± 0.5°C; then became warmer (13 ± 4°C). The water became more saline during the Late Colonial–Early Sedentary Period (A.D. 910–1025; sample F-610) with an estimated salinity of 1900 ± 700 ppm. However, toward the end of this episode (samples S-568 and S-577) a drastic fall in temperature (5 ± 1°C) and salinity (800 ± 300 ppm) was recorded.

The Sedentary Period (A.D. 1025–1275; samples F-560, F-563, F-575, F-582, F-591, F-643, F-700, and S-500) ostracode shell chemistry record may be divided into three epochs, the "Early Sedentary," "Sedentary," and "Late Sedentary." The "Early Sedentary" (1025–1105 A.D.; samples F-560 and

Table I. Ostracode shell chemistry, paleoenvironmental estiamtes using Palacios-Fest (1994b) experimentally derived multiple regression models for $^{m}(Mg/Ca)_{valve}$ and $^{m}(Sr/Ca)_{valve}$, and t-test analysis results.

Age	Sample	Valve	Wt. (ug)	m(Mg/Ca) (moles/l)	Mean	Estimated Temperature (°C)	Mean	m(Sr/Ca)	Mean	Estimated Salinity	Mean
700	F-567	1	6.2	0.0050	0.0053	8	8 ± 1	0.00028	0.00029	1000	1100 ± 500
		2	7.4	0.0059		9		0.00046		2000	
		3	6.8	0.0047		8		0.00032		1200	
		4	5.6	0.0073		11		0.00034		1400	
		5	6.3	0.0042		7		0.00017		500	
		6	4.7	0.0045		7		0.00017		500	
700	F-573	1	2.1	0.0119	0.0090	17	13 ± 4	0.00083	0.00055	3800	2400 ± 120
		2	3.8	0.0059		9		0.00053		2300	
		3	1.7	0.0127		18		0.00086		4000	
		4	1.9	0.0073		11		0.00035		1400	
		5	2.0	0.0104		15		0.00049		2100	
		6	2.5	0.0055		9		0.00022		800	
815	F-742	1	2.3	0.0214	0.0110	30	16 ± 7	0.00020	0.00032	700	1200 ± 500
		2	2.9	0.0076		11		0.00038		1500	
		3	2.6	0.0090		13		0.00048		2100	
		4	2.5	0.0131		19		0.00033		1300	
		5	2.3	0.0068		10		0.00022		700	
		6	2.6	0.0081		12		0.00031		1200	
855	S-924	1	4.7	0.0025	0.0026	5	5 ± 0.5	0.00025	0.00020	900	600 ± 200
		2	5.7	0.0019		4		0.00027		1000	
		3	4.7	0.0029		5		0.00019		600	
		4	4.3	0.0028		5		0.00015		400	
		5	4.4	0.0024		4		0.00017		500	
		6	4.6	0.0028		5		0.00024		800	
		7	4.9	0.0027		5		0.00019		600	
		8	4.1	0.0029		5		0.00013		300	
910	F-610	1	1.9	0.0143	0.0090	20	13 ± 4	0.00063	0.00045	2800	1900 ± 700
		2	2.1	0.0086		13		0.00042		1800	
		3	2.1	0.0087		13		0.00050		2100	
		4	2.1	0.0088		13		0.00059		2600	

		5	3.3	0.0053		8		0.00032		1200	
		6	2.8	0.0086		13		0.00025		900	
910	S-568	1	4.8	0.0030	0.0033	5	6 ± 3	0.00031	0.00025	1200	900 ± 300
		2	3.4	0.0032		5		0.00026		1000	
		3	5.1	0.0022		4		0.00023		800	
		4	4.7	0.0022		4		0.00021		700	
		5	5.2	0.0021		4		0.00027		1000	
		6	5.2	0.0078		12		0.00035		1400	
		7	4.3	0.0029		5		0.00016		400	
910	S-577	1	5.2	0.0028	0.0026	5	5 ± 1	0.00028	0.00022	1000	800 ± 300
		2	6.1	0.0021		4		0.00021		700	
		3	4.4	0.0036		6		0.00035		1400	
		4	6.3	0.0023		4		0.00024		800	
		5	6.1	0.0029		5		0.00022		700	
		6	6.0	0.0025		4		0.00013		300	
		7	5.4	0.0019		4		0.00014		400	
1025	F-560	1	5.3	0.0072	0.0084	11	12 ± 4	0.00056	0.00062	2400	2800 ± 220
		2	5.4	0.0113		16		0.00125		5900	
		3	3.1	0.0143		20		0.00144		6800	
		4	5.2	0.0068		10		0.00055		2400	
		5	5.7	0.0055		9		0.00041		1700	
		6	5.4	0.0059		9		0.00024		900	
		7	5.1	0.0089		13		0.00014		300	
		8	3.6	0.0076		11		0.00039		1600	
1025	F-575	1	6.3	0.0036	0.0062	6	10 ± 3	0.00038	0.00035	1500	1400 ± 500
		2	3.0	0.0104		15		0.00021		700	
		3	4.3	0.0056		9		0.00047		2000	
		4	3.8	0.0050		8		0.00036		1500	
		5	4.3	0.0042		7		0.00032		1300	
		6	4.1	0.0073		11		0.00042		1800	
		7	3.8	0.0065		10		0.00019		600	
		8	3.9	0.0071		11		0.00046		2000	
1105	F-582	1	2.4	0.0093	0.0074	14	11 ± 2	0.00064	0.00058	2800	2500 ± 500
		2	2.9	0.0070		11		0.00041		1700	
		3	2.6	0.0081		12		0.00061		2700	

(continued)

Table I. (*Continued*)

Age	Sample	Valve	Wt. (ug)	m(Mg/Ca) (moles/l)	Mean	Estimated Temperature (°C)	Mean	m(Sr/Ca)	Mean	Estimated Salinity	Mean
		4	3.5	0.0054		8		0.00070		3200	
		5	2.1	0.0073		11		0.00054		2300	
1105	F-591	1	2.8	0.0053	0.0091	8	13 ± 4	0.00028	0.00050	1100	2100 ± 110
		2	1.9	0.0118		17		0.00044		1900	
		3	2.3	0.0072		11		0.00054		2400	
		4	3.3	0.0056		9		0.00037		1500	
		5	2.7	0.0069		10		0.00034		1300	
		6	2.5	0.0153		22		0.00102		4800	
		7	2.4	0.0112		16		0.00061		2700	
		8	2.6	0.0097		14		0.00032		1200	
		9	2.1	0.0086		13		0.00054		2300	
1105	F-643	1	2.8	0.0074	0.0084	11	13 ± 2	0.00025	0.00046	900	1900 ± 600
		2	2.9	0.0072		11		0.00057		2500	
		3	2.1	0.0105		15		0.00058		2600	
		4	2.9	0.0089		13		0.00060		2700	
		5	2.4	0.0105		15		0.00038		1600	
		6	2.1	0.0082		12		0.00047		2000	
		7	1.9	0.0076		11		0.00042		1800	
		8	2.1	0.0074		11		0.00039		1600	
1120	F-700	1	3.8	0.0052	0.0048	8	8 ± 1	0.00035	0.00034	1400	1400 ± 500
		2	3.8	0.0060		9		0.00055		2400	
		3	3.9	0.0058		9		0.00041		1700	
		4	5.6	0.0036		6		0.00029		1100	
		5	4.1	0.0040		7		0.00024		900	
		6	3.9	0.0052		8		0.00027		1000	
		7	4.2	0.0038		6		0.00029		1100	
1275	S-500	1	3.3	0.0037	0.0041	6	7 ± 1	0.00029	0.00018	1100	500 ± 400
		2	3.7	0.0043		7		0.00020		700	
		3	2.9	0.0037		6		0.00008		100	
		4	2.1	0.0045		7		0.00015		400	
1365	F-529	1	3.1	0.0117	0.0084	17	12 ± 3	0.00079	0.00045	3600	1900 ± 100
		2	3.7	0.0094		14		0.00017		500	

		3	4.7	0.0077		12		0.00038		1600	
		4	5.1	0.0067		10		0.00041		1700	
		5	5.5	0.0063		10		0.00048		2100	
1425	F-513	1	4.3	0.0100	0.0116	15	17 ± 6	0.00098	0.00081	4500	3700 ± 800
		2	4.8	0.0071		11		0.00074		3300	
		3	4.1	0.0092		14		0.00050		2200	
		4	4.9	0.0103		15		0.00086		3900	
		5	2.4	0.0203		29		0.00088		4000	
		6	2.1	0.0128		18		0.00092		4200	
1889	F-777	1	2.7	0.0057	0.0058	9	9 ± 2	0.00049	0.00044	2100	1800 ± 700
		2	1.8	0.0090		13		0.00052		2300	
		3	2.3	0.0066		10		0.00026		900	
		4	4.1	0.0045		7		0.00049		2100	
		5	3.5	0.0039		6		0.00046		2000	
		6	3.0	0.0049		8		0.00036		1400	
		7	2.8	0.0037		6		0.00016		400	
		8	3.7	0.0054		8		0.00045		1900	
		9	3.1	0.0073		11		0.00070		3100	
		10	3.4	0.0064		10		0.00046		2000	
1889	F-778	1	1.8	0.0078	0.0053	12	8 ± 2	0.00032	0.00028	1200	1000 ± 400
		2	1.9	0.0078		12		0.00039		1600	
		3	3.2	0.0033		6		0.00026		1000	
		4	2.9	0.0036		6		0.00025		900	
		5	2.9	0.0047		7		0.00017		500	
		6	3.2	0.0056		9		0.00039		1600	
		7	3.0	0.0044		7		0.00017		500	
		8	2.7	0.0052		8		0.00025		900	
1889	F-779	1	5.1	0.0033	0.0035	6	6 ± 1	0.00033	0.00037	1300	1500 ± 200
		2	4.8	0.0028		5		0.00034		1300	
		3	2.3	0.0049		8		0.00040		1700	
		4	4.0	0.0031		5		0.00041		1700	

t-Test for related samples: n = 129	t-value	T-Dist.	p	rm
a) For temperature:	5.69	0.01	<0.05	>0.45
b) For salinity:	17.06	0.0004	<0.05	>0.8

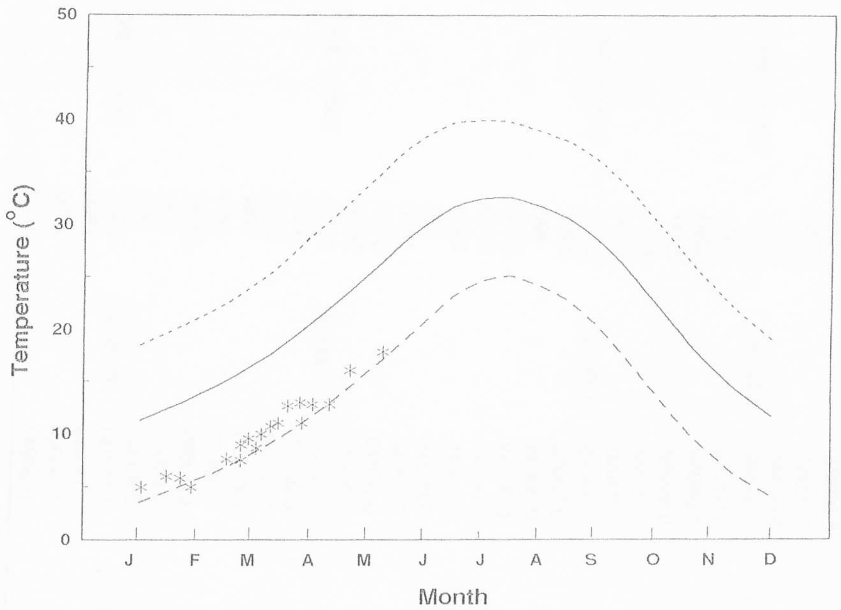

Figure 3. Monthly average mean (___), minimum (——), and maximum (---) temperature record. All data obtained from the National Climatic Data Center for the period of 1876–1995. Note that empirical temperature estimates (*) generated in this study fall within the interval between the minimum and mean average values.

F-575) was characterized by moderate to high salinity (1400 ± 500 to 2800 ± 2200 ppm) and temperature (12 ± 4°C). The "Sedentary" (1105–1120 A.D.; samples F-582, F-591, and F-643) showed slightly warmer temperatures (13 ± 4°C) and high salinity (2100 ± 1100 ppm). Finally, during the "Late Sedentary" (1120–1275 A.D.; samples F-700 and S-500) canal waters became colder (8 ± 1°C) and more dilute (1400 ± 500 ppm).

A drastic increase in water temperature and salinity is marked by the trace elements during the Classic Period (A.D. 1365–1425; samples F-529, and F-513) with temperature increasing to 17 ± 6°C and salinity ranging from 2200 to 3700 ± 800 ppm. In historic times (samples F-777, F-778, and F-779) the geochemical data suggest that canal water was colder (8 ± 2°C) and moderately saline with an estimated salinity of 1500 ± 200 ppm.

PALEOECOLOGIC INTERPRETATION

The most striking finding is the implication by trace element evidence that the Hohokam operated these canals mostly, if not exclusively, during the spring to take advantage of fresher water input, probably in an attempt to avoid or diminish salinization effects on agricultural fields. Ackerly (1989) indicates that, during the early Anglo occupation, the Tempe Canal received its largest discharge from late February to early April between 1895 and 1908, whereas the lowest discharges were recorded usually between June–July and September–October. Thus, the combination of trace element data and historic records provided a solid basis to assume that the Hohokam used these canals during the spring and early summer.

In addition, the main Hohokam crops, corn, beans, squash, native barley, and agave were mostly spring-summer products (Miksicek, 1989). Of these, beans were the least tolerant to increasing salinity—a slight increase in salinity (from 500 to 700 ppm) would produce a 10% yield reduction (Thompson, personal communication, Department of Agricultural Sciences, University of Arizona, 1994)—whereas native barley tolerated high TDS concentrations (>3700 ppm; Thompson, personal communication, 1994). Estimates of canal water salinity are reasonably higher (>1500 ppm) than the river's because the canals were subject to frequent flooding and subsequent desiccation that contributed to salinization. Miksicek (1989), Nials et al. (1989), and Gregory (1991) provided paleontologic and geomorphologic evidence of periodic flooding at Las Acequias during Hohokam occupation.

DISCUSSION

This article shows the significance of trace element shell chemistry as a tool to estimate the temperature and salinity of ancient waters. It also demonstrates the applicability of this technique to geoarchaeological research and its implications for understanding human/environment relationships.

The geochemical signatures presented in this study suggest that ostracode shell chemistry is a useful indicator of water chemistry and temperature changes in irrigation canals. Mg/Ca and Sr/Ca ratios follow trends that are consistent with our prior knowledge of Hohokam pre-history and southwestern climate (Petersen, 1988, 1992; Palacios-Fest, 1989). It is probable that the trends we observe in ostracode shell chemistry are responses to changes in temperature and water chemistry.

Inferred temperatures generated by Eq. (2) and salinities derived from Eq. (3) are in good agreement with spring temperatures (minimum mean monthly temperatures between February and early May: 7–17°C) and the Salt River TDS concentrations (800–1200 ppm) recorded at the end of the last century and early in this century (U.S. Department of Agriculture climatologic data files, 1897 to 1905).

Some important limitations in this study were the potential for redeposition of sediments in the canals and the sampling strategy originally followed which consisted in obtaining floatation samples from a large (bottom to top) interval. Sediment redeposition may result from the canal cleaning and maintenance before the agricultural season. Usually canals were scraped, and old sediments were only dumped to the sides (canal overbanks). Caution is crucial to identify reworked specimens before proceeding to any of the analyses in the future. The sampling strategy assumed that all infilling sediments in the canal were contemporaneous and did not account for successive episodes of canal flooding, which is unlikely because continuous deposition may occur for long periods of time. Samples in this study only suggest canal history over a broad time frame.

In conclusion, Hohokam canal ostracode shell chemistry correlates well with previously inferred climatic changes and modifications by human usage patterns as suggested by estimated temperatures (late winter–early summer). The empirical temperature and salinity estimates are well acquainted with historic records suggesting that experimentally derived coefficients may be a powerful tool to reconstruct ancient aquatic environments. It is proposed that future human impact research should include microstratigraphic sampling within and among canals to record individual canal operations and temporal correlation combined with ostracode shell chemistry.

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