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Continental Ostracode Paleoecology from the Hohokam Pueblo Blanco Area, Central Arizona

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Continental ostracodes provide a useful tool to reconstruct the history of agricultural activity from ancient Hohokam canals at Pueblo Blanco–Salt River site, Mesa, Arizona, both during Classic and pre-Classic Periods. Four ostracode assemblages are recognized from these canals suggesting periods of salination and dilution of the canal waters. Anthropogenic disturbance appears to be the major factor affecting ostracode occurrence in all canals. However, weak climatic signatures are also recorded suggesting that canal operation took place mostly during the late winter and early summer before the summer monsoon. © 1997 Academic Press Limited

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Introduction

The Hohokam, inheritants of a disputed origin, arrived to the Sonoran Desert as early as AD 1 or as late as AD 300. They may have been Mesoamerican migrants who introduced irrigation, or indigenous Archaic hunters and gatherers who learned agricultural techniques and pottery by word filtering up from the south along trade routes (Cheek, 1994). Most researchers support the latter hypothesis (Haury, 1976; Gummerman, 1991; Cheek, 1994). In the Sonoran Desert, the Hohokam developed the most complex irrigation system known in North America. Over 800 km of irrigation canals were dredged in the Salt River Valley including the large (main), medium (distribution) and small (lateral) canals. Main canals were 6–25 km long. A canal system (consisting of the three types) may have averaged 55 km in length. Some of the main canals were 12 m wide and 3 m deep (Katzer, 1989).

By the 1200s, this agricultural society reached its optimum organization; their main purpose was to operate one of the most ambitious systems in ancient North America. The earliest record of a canal yielded a date of AD 50 in Tempe, but it is not until around AD 600 that the Hohokam significantly dredged a canal system into the desert basin on either side of the Salt River. By the 1450s this culture barely existed (Ackerly, 1989). This magnificent agricultural system became history and a challenge for researchers to understand the Hohokam way of life and the reasons for their collapse. By this time the population had shrivelled to approximately one-tenth of what it had been. Over-population and mismanagement have been embraced as the most likely reasons for these people to disappear (Haury, 1976; Gummerman, 1991; Cheek, 1994). The canal system built by the Hohokam contains fossils that may provide some clues on how and when the Hohokam used (or maybe abused), and why they abandoned, their canals before the mid-15th century.

Amongst the fossils present in irrigation canals are ostracodes, microcrustaceans equipped with a calcareous carapace that is shed periodically as the organisms grow, until they reach maturity (Pokorný, 1978). Both juvenile and adult carapaces, consisting of two valves attached by a dorsal hinge, preserve well in the geological record and may be used as paleoenvironmental indicators (Delorme, 1969, 1989; De Deckker & Forester, 1988). Delorme (1989) has extensively used ostracodes to reconstruct paleoenvironments based on the theoretical faunal assemblage and the modern ecological tolerance (e.g. temperature, salinity, water chemistry). By this means Delorme has estimated the annual mean temperature and salinity of some Canadian lakes (e.g. Clearwater Lake). Forester (1983) has proposed that ostracodes are sensitive to changes in salinity and solute composition. Using these criteria he has suggested the possible ostracode anion relationship for several species of the genera *Limnocythere* and *Candona* in western North America.

Recently, continental ostracodes from prehistoric Hohokam irrigation canals have been used to reconstruct the history of canal operations (Palacios-Fest, 1989, 1994*a*). These studies have addressed possible human impacts on the environment before the arrival of Europeans in North America. Such impacts have been of concern to scientists for decades because of their possible effects on climate change. Thus, recognizing and separating anthropogenic and natural signals in the geoarchaeological record is of major

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significance for environmental reconstructions. Continental ostracode paleoecology has proven to be a reliable method of reconstructing irrigation canal conditions (e.g. water temperature, salinity, seasonal canal operation), since species occurrence and associations are closely related to the environmental conditions in which these organisms lived.

The Pueblo Blanco canals provide an important opportunity to investigate Hohokam agricultural practices. The objectives of the study were to elucidate canal water chemistry, intensity of land use, and human impacts on soil through application of ostracode paleoecology. Relative abundance and empirical paleosalinity indexes allowed the identification of patterns of canal operation and possibly the detection of cyclic agricultural events in the Hohokam occupation.

Previous research on prehistoric irrigation canals in the Phoenix Basin and modern canals in Magdalena, Sonora, Mexico, has shown the usefulness of ostracode analysis in the reconstruction of canal operations (Palacios-Fest, 1989, 1994*a*, 1994*b*). Data from modern canals collected by year-round sampling showed that ostracode assemblages vary in response to both seasonal fluctuations and human factors. For example, ostracode species assemblages changed through the year. This was originally thought to be climatically induced, but the assemblages were also found to respond to changes in water volume and flow which were human-induced. Some species (e.g. *Herpetocypris reptans*) which are usually restricted in certain areas of the study site were either common under slow flow, or absent in low water volumes (generally associated with waterlogging or salination). Such studies of modern ostracode assemblages have thus provided baseline information for characterizing and distinguishing climatic and human factors in ostracode assemblages from relict canals.

Ostracode analysis of prehistoric canals can be used to reconstruct the environmental conditions in which these organisms grew. Further, by comparing these data with ostracode data from modern canals, it is feasible to make interpretations of the factors affecting ostracodes in human-disturbed environments (Taylor, 1991; Smith & Forester, 1994). It has been demonstrated that paleoclimatic and anthropogenic signatures in Hohokam Canals can be distinguished using ostracode paleoecology (Palacios-Fest, 1989, 1994*a*). More recent studies may provide clues to the seasonal operation of irrigation canals in Hohokam occupation (Palacios-Fest, 1994*b*). These studies provide the geochemical database used to estimate temperature and salinity of agricultural water used by the Hohokam.

The Pueblo Blanco Location

The study site is at the intersection of Alma School Road and McDowell Road in the Salt River Indian Reservation in the north-eastern portion of the

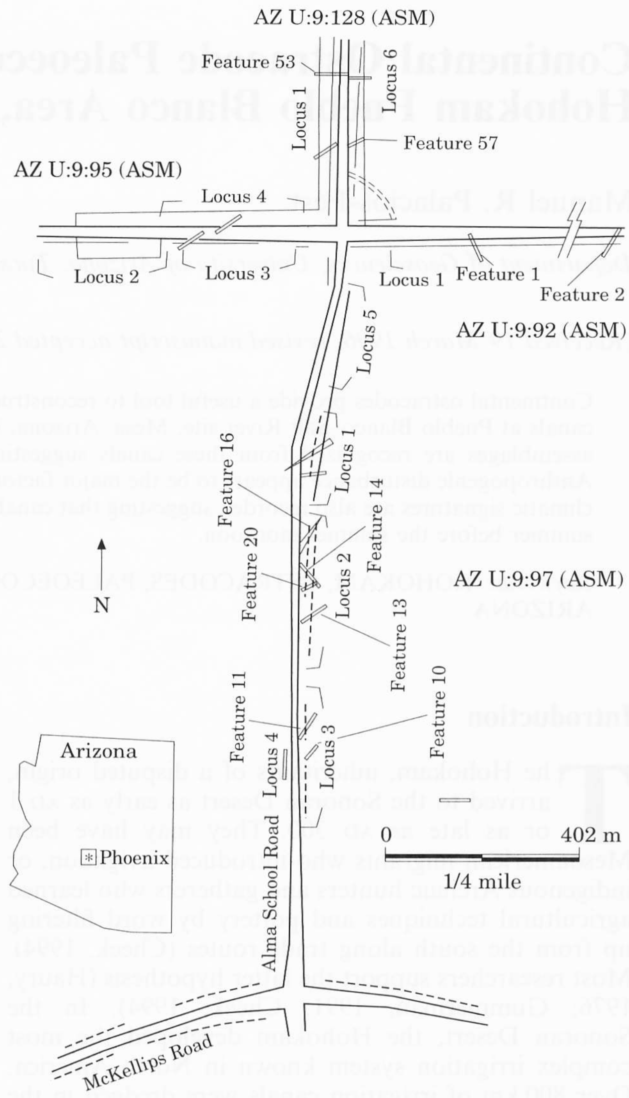


Figure 1. Location map of the Pueblo Blanco archaeological site in Mesa, Arizona. Hohokam irrigation canals exposed during the enlargement of the Alma School Road between McDowell and McKellips roads on the Salt River Pima-Maricopa Indian Community (SRPMIC), were dug along the north-east rim of the Salt River.

Phoenix Basin (Figure 1). Lowe (1964) includes the Phoenix Basin in the northern sector of the Sonoran Desert Life Zone. It includes the desert areas of the Gila and Salt River valleys where they debouch from the mountains on the north-eastern periphery, and extends south to the northern reaches of the Santa Cruz River Valley (Doyel, 1995). The Phoenix Basin, core area of the Hohokam culture, has an approximate area of 6440 km^2 and includes some secondary drainages on its north-western quarter and part of the lower Santa Cruz River (Doyel, 1991).

Part of the Basin and Range physiographic province, the Phoenix Basin also contains alluvial deposits of unconsolidated gravels, sands, and silts that range in age from the mid-Tertiary to the present. Five terraces along the Salt River occur in the vicinity of the Phoenix Basin (Péwé, 1978; Péwé, Wellendorf & Bales, 1986). From youngest to oldest, these terraces are the active floodplain, followed by the Lehi, the Blue Point, the Mesa, and the Sawik Terraces. Only the Lehi and the Mesa Terraces are present in the study area. The Lehi Terrace is about 1 m above the Salt River flood plain and about 2 km wide. It consists of weakly developed and unconsolidated sands, silts, clays, and gravels characteristic of high-energy channel deposits (Huckleberry, 1995). The Mesa Terrace is higher and wider, rising 80 m above the Lehi Terrace. It is composed of more mature and consolidated argillic horizons with carbonate and calcified silt nodules and masses (Huckleberry, 1995). All these soils are agriculturally productive, although the Lehi Terrace soils are richer due to over-bank flooding by the Salt River.

Summary of Canal Sedimentology, Stratigraphy and Chronology

Table 1 summarizes the canal and sample identification by individual canal, archaeomagnetic and radiocarbon dates, stratigraphic position of samples within canals, other fossils present, sediment type, colour and canal type. Huckleberry (1995) describes in detail the sedimentological composition of canal samples used in this study. He arbitrarily identifies three canal sizes based on their cross-sectional areas: $<1{\cdot}0\ m^2$, $1{\cdot}0$–$3{\cdot}9\ m^2$, and $>4{\cdot}0\ m^2$. The largest canals were aligned west to south-west and were probably main and large distribution canals, whereas the smaller canals were probably small distribution and lateral canals. The Lehi Terrace holds the largest canals, although enlargement may have resulted from fluvial scouring of the unconsolidated soils during normal canal operation.

Canal stratigraphy is the result of sediment load and the flow regime. The Salt River contributed a mixed sediment load before the river's damming (Forbes, 1902). The Pueblo Blanco canal sediments consisted of coarse sand to finer grain sizes indicating that controlled stream-flows limited the size of sediments entering the canals (Huckleberry, 1995). The depositional sequences recorded from Pueblo Blanco ranged from massive to texturally contrasting strata. Coarser sediments occur in the Lehi Terrace canals than in the Mesa Terrace, probably because of their relative non-cohesiveness and their proximity to the headgate.

Stratigraphical, archaeomagnetical and radiocarbon analyses suggested that the Lehi Terrace canals at State Route 87 dated to the Classic Period, AD 1100–1450 (Eighmy, Cooperider & LaBelle, 1994). Although with a wide age range, the canals at Pueblo Blanco also indicate a Classic Period age, post-AD 1300 (Eighmy, Cooperider & LaBelle, 1994). Despite some discrepancies noted by Huckleberry (1995) it is likely that the Lehi Canal System, located on the south side of the Salt River, was built during the Classic Period.

Materials and Methods

Sediment samples (43) from Pueblo Blanco Canals at the Alma School Data Recovery Project area were analysed for ostracode content (Table 1). Sampling intervals within canals were approximately 2·5 cm. Of these samples, 38 contained enough ostracodes for paleoecological analysis. Ostracode samples were selected to reconstruct individual canal history, to correlate equivalent strata between different canals and to define periodicity (seasonality) of canal operation during Hohokam occupation (Figure 2).

Samples were collected from 10 canals in four loci located about 2 km north–north-west of the Salt River. At AZ U:9:92 (ASM)-Locus 1, situated at the edge of the Lehi and Mesa Terraces, one lateral or small distribution canal (Feature 1) and one small distribution (Feature 2) canal were sampled. AZ U:9:97 (ASM)-Loci 2 and 3, located 0·5 km south of the McDowell Road on the Lehi Terrace contained four distribution canals (Features 10, 11, 13 & 20) and two lateral canals (Features 14 & 16). AZ U:9:128 (ASM)-Locus 1, several hundred metres north of McDowell Road, contained only one distribution canal (Feature 53). AZ U:9:95 (ASM)-Locus 6, located in the north-east corner of the intersection of McDowell and Alma School Roads, contained one distribution canal (Feature 57).

Samples were prepared using a modified version of the protocol described by Forester (1991). Sediment residuals were analysed under a low power stereoscopic microscope. Routine study of all 38 fossiliferous samples was performed to determine fossil content and faunal assemblages. Total and relative abundance were recorded. Flowing systems (e.g. rivers, channels, irrigation canals) usually hold small sample sizes; thus, taphonomic criteria are convenient in determining the origin of specimens (Forester, 1988; Delorme, 1989; Taylor, 1991). Fragmentation, abrasion, and the ratios of carapaces:valves and juveniles:adults were used to define if the sample was reliable for this study. Based on species abundance, a paleosalinity index was used to establish the canal operation history (see Palacios-Fest, 1994*a*). The paleosalinity index (SI) was derived from the equation:

$$SI = (4(\%\ \textit{L. staplini}) + 3(\%\ \textit{C. vidua}) + 2(\%\ \textit{C. patzcuaro}) + (\%\ \textit{I. bradyi})) - ((\%\ \textit{H. reptans}) + 2(\%\ \textit{P. pustulosa}) + 3(\%\ \textit{D. stevensoni})).$$

The index weights species with incrementally higher salinity tolerances positively and weights species with incrementally lower salinity tolerances negatively.

The Ostracode Record

Table 2 summarizes the species present in and environmental conditions controlling ostracode assemblages

Table 1. Canal and sample identification

AZ State Museum #	Locus #	Feature #	Sample #	Years (AD) Min	Max	AVG	Stratigraphic position	Height from canal base (cm)	Other fossils		Sediment type	Colour	Canal type
AZU:9:92	1	1	ACS-1-1	1325	1725	1525	Bottom	0–2·5	BARREN		Gravel/sand	Reddish	Lateral(?)
			ACS-1-2				Next to bottom	5–7·5	Fish	Molluscs	Gravel/sand	Reddish	
			ACS-1-3				Next above	10–12·5	Molluscs		Gravelly coarse sand	Reddish-brown	
			ACS-1-4				Middle	15–17·5	BARREN		Gravelly coarse sand	Reddish-brown	
			ACS-1-5				Next to top	20–22·5	Molluscs		Gravelly coarse sand	Reddish-brown	
			ACS-1-6				Top	25–27·5	Molluscs		Medium/fine sand+silt	Reddish-brown	
		2	ACS-2-1	Undated			Bottom	0–2·5	Molluscs	Gravelly coarse sand	Reddish-brown	Lateral(?)	
AZU:9:97	3	10	ACS-10-1	1200	1675	1438	Bottom	0–2·5	Molluscs		Fine sand+silt+clay	Reddish-brown	Distribution
		11	ACS-11-1	1300	1675	1488	Bottom	0–2·5	Charophytes		Gravelly coarse sand	Reddish	Distribution
			ACS-11-2				Next to bottom	15–17·5	Charophytes	Molluscs	Coarse/medium sand+silt	Reddish	
			ACS-11-3				Middle	30–32·5	Charophytes	Molluscs	Coarse/medium sand+silt	Reddish	
			ACS-11-4				Next to top	45–47·5	Charophytes	Molluscs	Coarse/medium sand+silt	Reddish	
			ACS-11-5				Top	58–60·5	Charophytes	Molluscs	Coarse/medium sand+silt	Reddish	
	2	13	ACS-13-1	1450	1800	1625	Bottom	0–2·5	Molluscs		Gravelly coarse sand	Reddish	Distribution
			ACS-13-2				Next to bottom	2·5–5	BARREN		Gravel/sand	Reddish	
			ACS-13-3				Middle sand	5–7·5	BARREN		Gravelly coarse sand	Reddish	
			ACS-13-4				Clay pocket	10–12·5	Molluscs		Medium/fine sand+silt	Reddish	
			ACS-13-5				Top clay	47·5–50	BARREN		Gravelly coarse sand	Reddish	
		14	ACS-14-1	1350	1700	1525	Bottom	0–2·5	Molluscs		Coarse/medium sand+silt	Reddish	Lateral
			ACS-14-2				Next to bottom	10–12·5	Molluscs		Medium/fine sand+silt	Orange	
			ACS-14-3				Top	20–22·5	Molluscs		Medium/fine sand+silt	Orange	
		16	ACS-16-1	1200	1700	1450	Bottom	0–2·5	Molluscs	Medium/fine sand+silt	Orange		
			ACS-16-2				Next to bottom	9–11·5	Molluscs	Fine sand+silt+clay	Yellowish		
			ACS-16-3				Right wall clay pocket	17–19·5	Molluscs		Fine sand+silt–clay	Yellowish	
			ACS-16-4				Left wall clay pocket	16–18·5	Molluscs		Fine sand+silt+clay	Yellowish	
			ACS-16-5				Top sand	22·5–25	Molluscs		Fine sand+silt+clay	Yellowish	
		20	ACS-20-1	1200	1700	1450	Bottom	0–2·5	Molluscs	Gravelly coarse sand+silt	Brownish-red	Distribution	
AZU:9:128	1	53	ACS-53-1	650	1000	825	Bottom	0–2·5	Charophytes		Gravelly coarse sand+silt	Brownish-red	Distribution
			ACS-53-2				Next to bottom	5–7·5	Charophytes	Molluscs	Fine sand+silt+clay	Brownish-red	
			ACS-53-3				Next above	10–12·5	Charophytes	Testate amoeba	Fine sand+silt+clay	Brownish-red	
			ACS-53-4				Next under middle	15–17·5	Charophytes	Testate amoeba	Fine sand+silt+clay	Brownish-red	
			ACS-53-4′				Middle	17·5–20	Charophytes	Molluscs	Fine sand+silt+clay	Brownish-red	
			ACS-53-5				Next above middle	20–22·5	Charophytes	Molluscs	Fine sand+silt+clay	Brownish-red	
			ACS-53-6				Next above	25–27·5	Charophytes	Molluscs	Fine sand+silt+clay	Brownish-red	
			ACS-53-7				Next above	30–32·5	Charophytes	Molluscs	Fine sand+silt+clay	Brownish-red	
			ACS-53-8				Next to top	35–37·5	Charophytes	Molluscs	Fine sand+silt+clay	Brownish-red	
			ACS-53-9				Top	40–42·5	Charophytes	Molluscs	Fine sand+silt+clay	Brownish-red	
AZU:9:95	6	57	ACS-57-1	650	1000	825	Bottom	0–2·5	Molluscs		Fine sand+silt+clay	Reddish	Distribution(?)
			ACS-57-2				Next to bottom	5–7·5	Charophytes	Molluscs	Silt+clay+pyrite nodules	Brownish-grey	
			ACS-57-3				Next above	10–12·5	Charophytes	Molluscs	Silt+clay+pyrite nodules	Brownish-grey	
			ACS-57-4				Middle	15–17·5	Charophytes	Molluscs	Silt+clay+pyrite nodules	Brownish-grey	
			ACS-57-5				Next to top	20–22·5	Molluscs		Silt+clay+pyrite nodules	Brownish-grey	
			ACS-57-6				Top	25–27·5	Molluscs		Silt+clay+pyrite nodules	Brownish-grey	

Site number is included in this table but not in remaining tables due to space limitations. Archaeomagnetic dates are those of Doyel (1995). Relative and absolute stratigraphic position of samples are shown for each canal. The occurrence of other fossils is reported as additional information obtained during this study. Sediment type, colour and canal type resulted from personal interpretations.

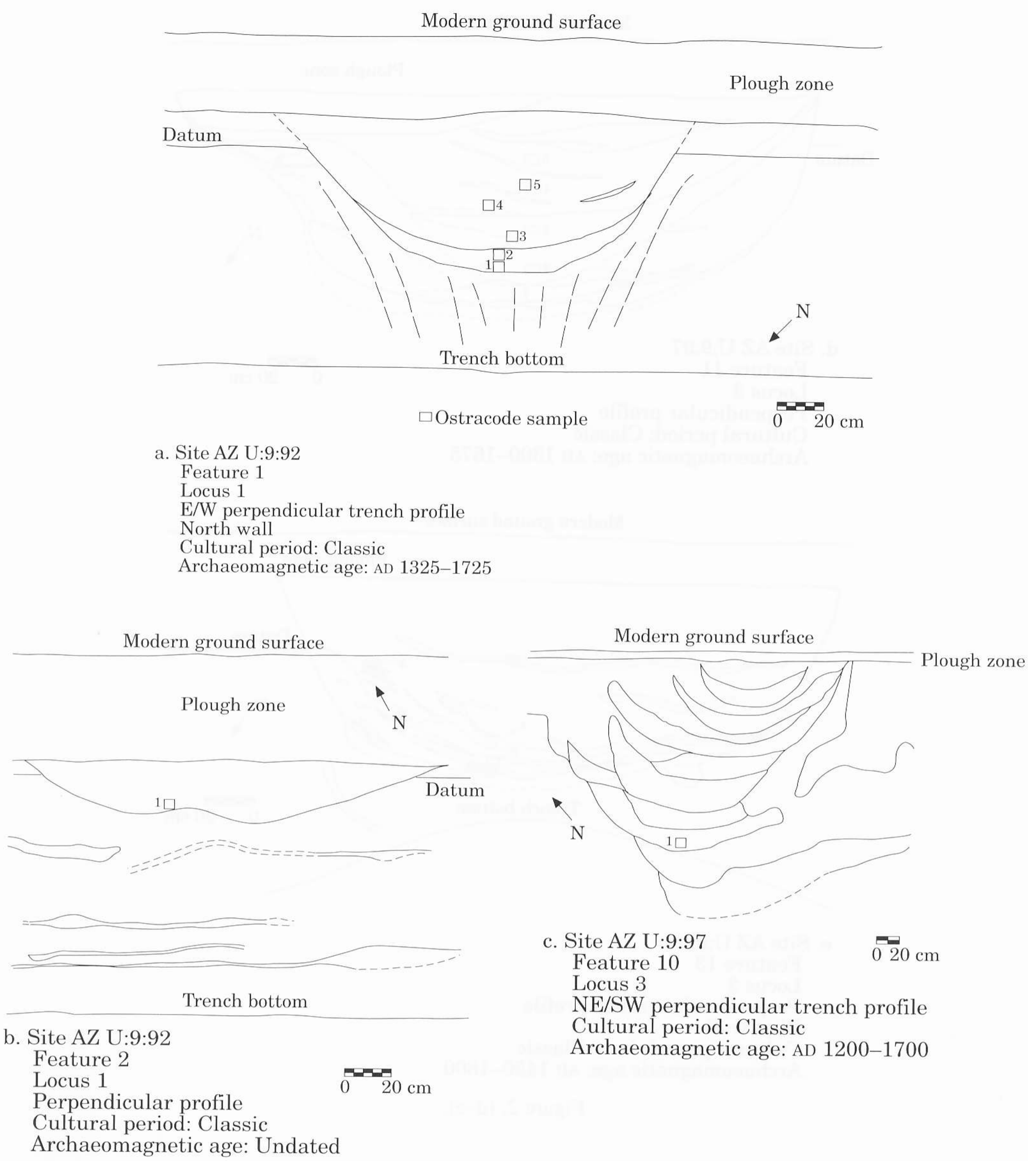


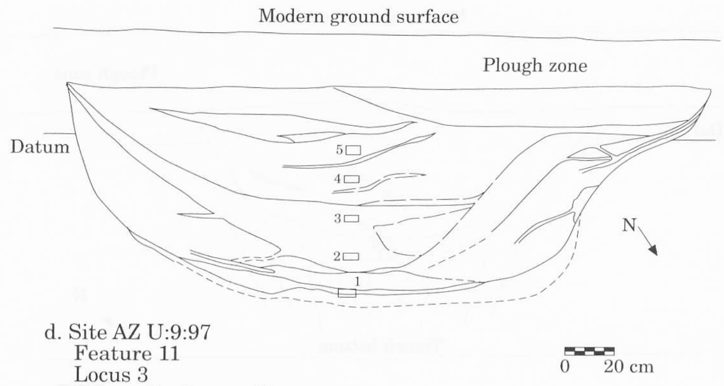
Figure 2. (a–c).

Figure 2. Schematic canal stratigraphy and ostracode sample horizons. Canal features are presented by site and locus number. Most canals represent the Classic Hohokam Period (a–h) but two canals are older and belong to the Pioneer–Colonial Period (i, j).

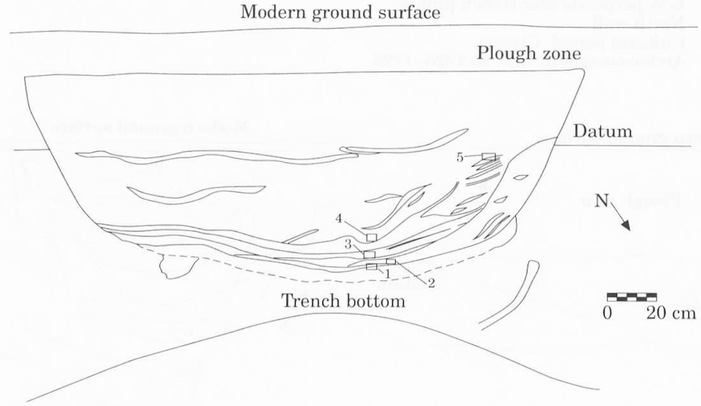
that occurred in the Pueblo Blanco canals. Of the seven species present, the dominant species, *Limnocythere staplini*, was absent only in one sample. *Cypridopsis vidua* and *Candona patzcuaro* were also common in most canals. Other species (*Ilyocypris bradyi*, *Herpetocypris reptans*, *Physocypria pustulosa* and *Darwinula stevensoni*) occurred less frequently. Based on the occurrence and relative abundance of these species (Table 3), four assemblages (I–IV) were recognized (Table 4; see Palacios-Fest, 1994*a*, for characteristics of the individual assemblages); all of these characterized water pathway types I (dilute) and II (Ca-enriched waters dominated additionally by Na^+, Mg^{2+} and SO_4^{2-}) of Eugster & Hardie (1978).

Hem's (1985) water analyses of the modern Salt and Gila Rivers showed near-equivalent proportions of bicarbonate and Ca, with the latter slightly dominant. The chemistry of these modern water types inferred through ostracode paleoecology was consistent. Main canal waters evolved from type I to type II as they flooded smaller canals (distribution and lateral) and were subject to gradual evaporation. The replacement of *C. patzcuaro* by *L. staplini* shows this transition.

The ostracode absolute and relative abundance, and paleosalinity index values, were computed for each sample (Table 3). All fossil samples were characterized by a small population (10–360 individuals/g of sediment) and low diversity (one to seven species). The



d. Site AZ U:9:97
Feature 11
Locus 3
Perpendicular profile
Cultural period: Classic
Archaeomagnetic age: AD 1300–1675



e. Site AZ U:9:97
Feature 13
Locus 2
Perpendicular trench profile
West wall
Cultural period: Late Classic
Archaeomagnetic age: AD 1450–1800

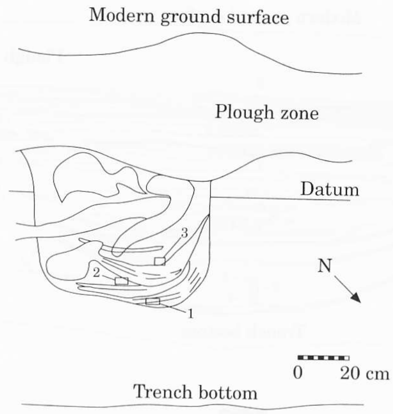
Figure 2. (d–e).

sample characteristics, with their assemblage type and interpretation, are presented in Table 4. Small sample size appeared to be the result of the degree of energy and water permanence as observed in modern drainages (Taylor, 1991), yet ostracode occurrence may be attributed to transport or local growth. Taphonomic features (e.g. fragmentation, abrasion, and the ratios of carapaces:valves and juveniles:adults) were used to establish the individuals' allochthony (transport) or autochthony (native) and the significance of the data (Delorme, 1969, 1989; Forester, 1988).

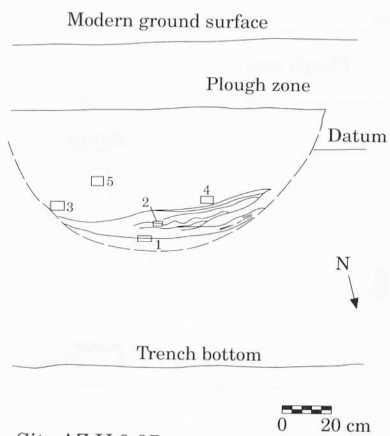
For each canal, the sequence of species distribution and paleoecology was used to interpret the sequence of the environments in the canals. The sequence of ostracode distribution is presented in three parts (Figure 3(a)–(h)): the charts at the left show the relative abundance of each species by depth; the paleosalinity index indicates the relative salinity gradients among canals; and pie diagrams illustrate the proportional occurrence of species present in each sample (used to classify the distribution into an assemblage type).

Three canals, Feature 2 at AZ U:9:92 (ASM) and Features 10 and 20 at AZ U:9:97 (ASM), were represented by only one sample (Figure 4). Sample ACS-2-1 (Feature 2) contained only *L. staplini* (a halobiont ostracode: Palacios-Fest, 1994*b*), and was grouped into Assemblage I (Table 4). Sample ACS-10-1 (Feature 10) contained a richer fauna: *L. staplini* was the dominant species, followed by *C. patzcuaro* and minor occurrences of *C. vidua*, *I. bradyi* and *H. reptans* (categorized as Assemblage I). In contrast, the sample from Feature 20 (ACS-20-1) contained only two species: *C. patzcuaro* (dominant) and *L. staplini*. It was classified into Assemblage III.

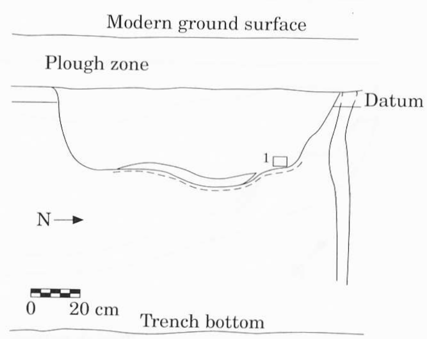
Feature 1 at AZ U:9:92 (ASM) contained six samples (Figure 3(a)). Four species (*L. staplini*, *C. patzcuaro*, *C. vidua* and *H. reptans*) occurred in this canal. The paleosalinity index was dominated by



f. Site AZ U:9:97
Feature 14
Locus 2
Perpendicular trench profile
SE wall
Cultural period: Classic
Archaeomagnetic age: AD 1350–1700



g. Site AZ U:9:97
Feature 16
Locus 2
Perpendicular trench profile
Cultural period: Classic
Archaeomagnetic age: AD 1200–1700



h. Site AZ U:9:97
Feature 20
Locus 2
Perpendicular profile
Cultural period: Classic
Archaeomagnetic age: AD 1200–1675

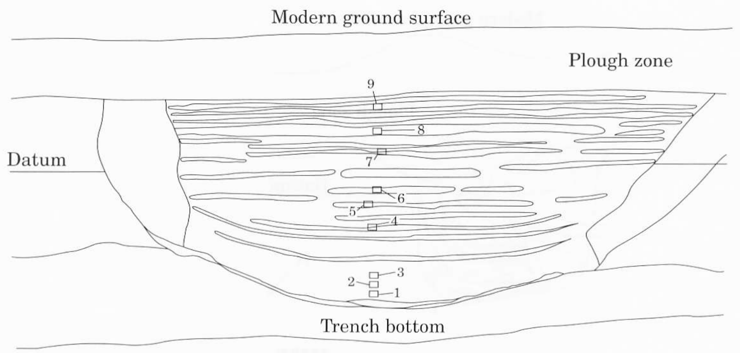
Figure 2. (f–h).

C. patzcuaro although other species were also significant. Two assemblages were identified throughout this canal history. At an early stage (I), Assemblage II (near-equivalent occurrence of *L. staplini*, *C. patzcuaro* and *C. vidua*) characterized the canal, but in the next stage (II) the microfauna was consistent with Assemblage III (*C. patzcuaro*-dominated).

Five species were present in Feature 11 at AZ U:9:97 (ASM): *L. staplini*, *C. vidua*, *C. patzcuaro*, *H. reptans* and *D. stevensoni* (Figure 3(b)). *L. staplini* and *C. patzcuaro* dominated the assemblage, with relatively consistent appearances of *C. vidua* and the occasional occurrence of *H. reptans* and *D. stevensoni*. The paleosalinity index was dominated by *L. staplini*, but other species were also important (*C. patzcuaro* and *C. vidua*). The pie diagrams illustrate that Feature 11 evolved from Assemblage I (*L. staplini*-dominated) to Assemblage II (near-equivalent proportions of *L. staplini*, *C. patzcuaro* and *C. vidua*). Thus, two stages (I and II) were also recognized in this canal.

Four species (*L. staplini*, *C. vidua*, *D. stevensoni* and *H. reptans*) characterized the remains from Feature 13 at AZ U:9:97 (ASM); however, the species were poorly represented (Figure 3(c)). *L. staplini* was the dominant species and figured heavily in the paleosalinity index. Feature 13 varied from Assemblage IV (*L. staplini*/*D. stevensoni*-dominated) to Assemblage I (*L. staplini*-dominated).

Feature 14 at AZ U:9:97 (ASM) showed a much greater diversity of species (Figure 3(d)). All seven species identified in the Alma School Road Project occurred in this canal. *L. staplini* was the dominant



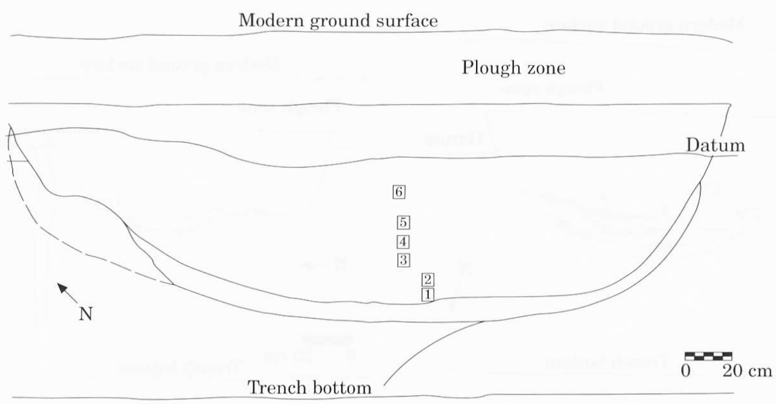


Figure 2. (i–j).

Table 2. Generalized environmental conditions of species present in this study

Species	Habitat	Life cycle (weeks)	Permanence	Temperature	Salinity (ppm)	Chemistry
Limnocythere staplini	Lake or pond	4–6	Perennial or ephemeral	Thermophillic	500–75,000	Ca-rich waters
Cypridopsis vidua	Lake, pond or spring	4–8	Perennial or ephemeral	Eurythermic	100–4000	Eurytopic
Candona sp. cf. *C. patzcuaro*	Lake or pond	10–16	Perennial or ephemeral	Eurythermic	200–5000	Eurytopic
Ilyocypris bradyi	Stream or pond	10–16	Perennial or ephemeral	Thermophillic	100–4000	Eurytopic
Herpetocypris reptans	Stream or pond	8–10	Perennial or ephemeral	Eurythermic	100–4000	Freshwater to Ca-rich
Physocypria pustulosa	Lake or pond	6–8	Perennial or ephemeral	Thermophillic	100–600	Freshwater to Ca-rich
Darwinula stevensoni	Lake or pond	>20	Perennial	Eurythermic	50–2000	Freshwater to Ca-rich

Habitat of species is where these organisms live in natural conditions. Life cycle is the average time required for each species to reach maturity (although this value may change greatly, a reasonable estimate is presented in this table). Permanence refers to the lasting of the water body. With respect to temperature the term thermophillic is applied to organisms that prefer to live at temperatures greater than 20°C, and the term eurythermic applies to those organisms adapted to a broad range of temperatures. Salinity and water chemistry are those shown by Palacios-Fest (1989, 1994*a*).

Table 3. Pueblo Blanco ostracode species total and relative abundance and salinity index generated in this study

Sample #	Depth (cm)	Ostracodes/g (g)	*Limnocythere staplini*		*Cypridopsis vidua*		*Candona patzcuaro*		*Ilyocypris bradyi*		*Herpetocypris reptans*		*Physocypria pustulosa*		*Darwinula stevensoni*		Salinity index
			#	%	#	%	#	%	#	%	#	%	#	%	#	%	
ACS-1-1	0	0															
ACS-1-2	5	6	2	33	2	33	2	33									297
ACS-1-3	10	3					3	100									200
ACS-1-4	15	0															
ACS-1-5	20	33	4	12			26	79			3	9					197
ACS-1-6	25	11	4	36			7	64									272
ACS-2-1	0	12	12	100													400
ACS-10-1	0	361	222	61	12	3	113	31	11	3	3	0·8					325
ACS-11-1	0	0															
ACS-11-2	15	70	48	69	11	16	10	14							1	1	349
ACS-11-3	30	19	14	74			5	26									348
ACS-11-4	45	13	8	62	3	23	3	23									363
ACS-11-5	58	19	7	37	5	26	7	37			1	5					295
ACS-13-1	0	4	2	50	1	25	0	0							1	25	200
ACS-13-2	2·5	0					0	0									
ACS-13-3	5	0					0	0									
ACS-13-4	10	98	94	96			0	0			4	4					380
ACS-13-5	47	0					0	0									
ACS-14-1	0	41	35	85			1	2			1	2	1	2	4	10	310
ACS-14-2	10	107	75	70	18	17	0	0	4	4	0	0			10	9	308
ACS-14-3	20	161	102	63			1	0·6	1	0·6	6	4			51	32	154
ACS-16-1	0	361	268	74	23	6	18	5			15	4	12	3	25	7	275
ACS-16-2	9	239	207	87	12	5	3	1			2	0·8	4	2	11	5	341
ACS-16-3	17	300	269	90	12	4	2	0·6					3	1	10	3	358
ACS-16-4	26	57	42	74	10	18	1	2					1	2	1	2	346
ACS-16-5	22·5	50	40	80	3	6	1	2							6	12	306
ACS-20-1	0	6	2	33			4	67									266
ACS-53-1	0	42	27	64	5	12	11	26									344
ACS-53-2	5	140	68	49	17	12	56	40									312
ACS-53-3	10	20	9	45	2	10	9	45									300
ACS-53-4	15	186	86	46	16	9	73	39	6	3	5	3					292
ACS-53-4′	17·5	130	84	65	5	4	38	29	3	2							333
ACS-53-5	20	110	49	45	9	8	46	42	6	5							294
ACS-53-6	25	82	48	59	5	6	26	32	3	4							321
ACS-53-7	30	95	50	53	5	5	39	41	1	1							310
ACS-53-8	35	92	46	50	2	2	41	45	2	2					1	1	295
ACS-53-9	40	53	23	43	3	6	25	47	2	4					1	2	280
ACS-57-1	0	190	18	9	8	4	162	85	1	0·5							219
ACS-57-2	5	576	60	10	17	3	495	86	4	0·6							225
ACS-57-3	10	226	54	24	1	0·4	168	74	2	0·8	1	0·4	2	0·8			243
ACS-57-4	15	26	3	12	1	4	18	69			3	12					186
ACS-57-5	20	40	4	10	1	3	33	83			2	5					210
ACS-57-6	25	92	11	12	1	1	80	87									225

The salinity index is a relative estimate of salinity tolerance based on Palacios-Fest *et al.*'s (1993) equation, according to the hydrochemically significant species (see text for explanation).

Table 4. Ostracode assemblages and paleoenvironments

Assemblage	Sample	*L. staplini*	*C. vidua*	*C. patzcuaro*	*I. bradyi*	*H. reptans*	*P. pustulosa*	*D. stevensoni*	Environment
I	ACS-2-1	1							Hypersaline, ephemeral
	ACS-10-1	1	3	2	4	5			Moderately saline, long water permanence
	ACS-11-2	1	2	3				4	Moderately saline, long water permanence
	ACS-11-3	1		2					Moderately to highly saline, long water permanence
	ACS-11-4	1	2	3					Moderately saline, long water permanence
	ACS-13-4	1				2			Hypersaline, ephemeral
	ACS-16-2	1	2	6		5	4	3	Saline, periodic water permanence
	ACS-16-3	1	2	4		5	5	3	Highly saline, short water permanence
	ACS-16-4	1	2	3			4	5	Moderately saline, increasing evaporation
	ACS-53-1	1	3	2					Slightly to moderately saline, long water permanence
	ACS-53-4′	1	3	2	4				Slightly to moderately saline, long water permanence
	ACS-53-6	1	3	2	4				Slightly to moderately saline, long water permanence
II	ACS-1-2	1	1	1					Moderately saline, long water permanence
	ACS-11-5	1	2	1		3			Slightly saline, long water permanence
	ACS-53-2	1	3	2					Slightly saline, long water permanence
	ACS-53-3	1	2	1					Diluted waters, long water permanence
	ACS-53-4	1	3	2	4	5			Stream diluted waters, long water permanence
	ACS-53-5	1	3	2	4				Stream diluted waters, long water permanence
	ACS-53-7	1	3	2	4				Stream diluted waters, long water permanence
	ACS-53-8	1	3	2	4			5	Diluted waters, long water permanence
III	ACS-1-3			1					Diluted waters, long water permanence
	ACS-1-5	2		1		3			Slightly saline, long water permanence
	ACS-1-6	2		1					Moderately saline, long water permanence
	ACS-20-1	2		1					Moderately saline, long water permanence
	ACS-53-9	2	3	1	4			5	Stream diluted waters, long water permanence
	ACS-57-1	2	3	1	4				Stream diluted waters, long water permanence
	ACS-57-2	2	4	1	3				Stream diluted waters, long time canal operation
	ACS-57-3	2	5	1	4	6	3		Slightly saline, long water permanence
	ACS-57-4	2	4	1		3			Diluted waters, long water permanence
	ACS-57-5	2	4	1		3			Diluted waters, long water permanence
	ACS-57-6	2	3	1					Diluted waters, long water permanence
IV	ACS-13-1	1	2					3	Moderately saline, short water permanence
	ACS-14-1	1		3		4	5	2	Saline, periodic water permanence
	ACS-14-2	1	2		4			3	Moderately to highly saline, short water permanence
	ACS-14-3	1		4	5	3		2	Moderately saline, periodic water permanence
	ACS-16-1	1	3	4		5	6	2	Moderately saline, periodic water permanence
	ACS-16-5	1	3	4				2	Moderately saline, periodic water permanence

Assemblage I: *L. staplini*-dominated, type II water (Ca^{2+}-enriched/HCO_3^--depleted water; Na^+, Mg^{2+}, SO_4^{2-} or Na^+, Mg^{2+}, Cl^-) low to hypersaline conditions; Assemblage II: nearly equal proportion of *L. staplini–C. vidua–C. patzcuaro*, type I (Ca^{2+}, (Mg^{2+}), and HCO_3^{2-}-dominated water; freshwater to low salinity) to type II water; Assemblage III: *C. patzcuaro*-dominated, type I to type II water; Assemblage IV: *L. staplini–D. stevensoni*-dominated, type I to type II water.
Numbers 1 to 6 express ranked occurrence within sample.

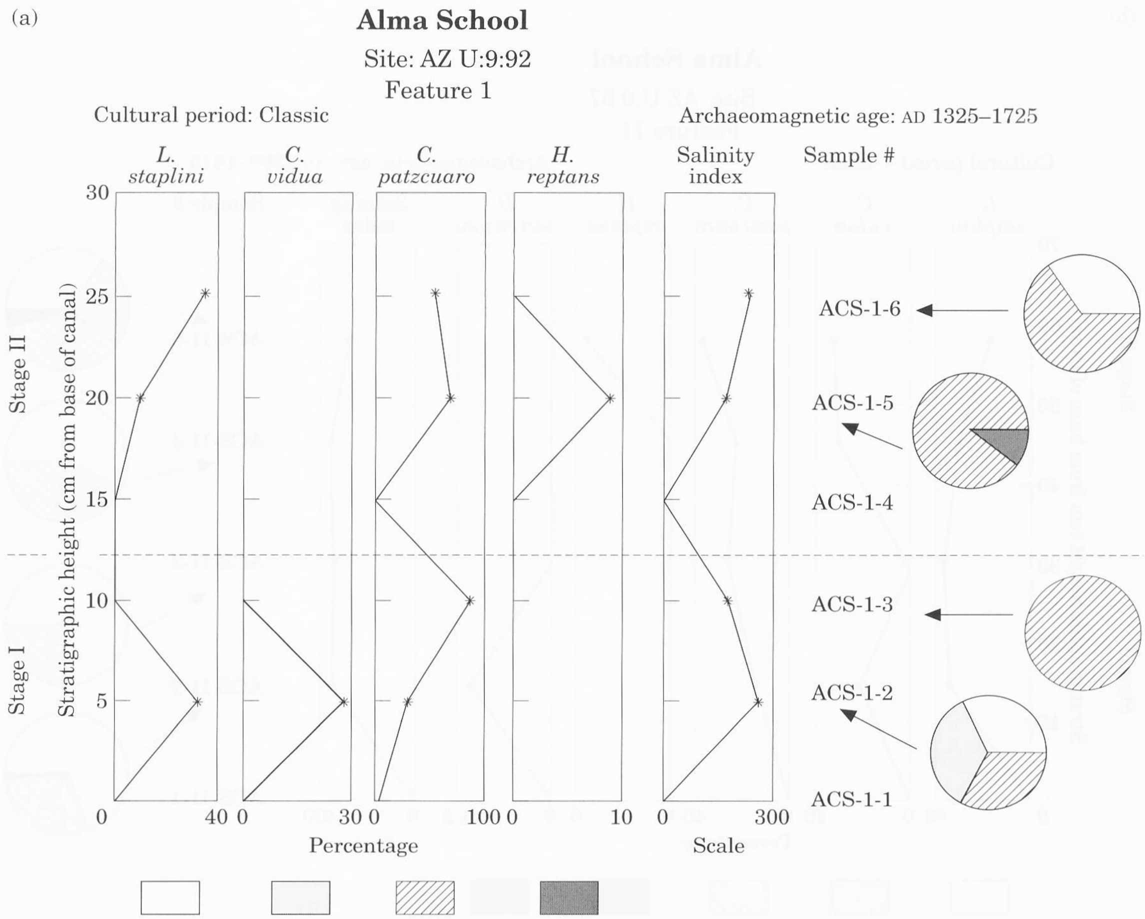


Figure 3. (a).

Figure 3. (a–g) Ostracode relative abundance, relative salinity index trends and pie diagrams showing ostracode proportions by sample from: (a) Feature 1, located in site AZ U:9:92; (b) Feature 11, located in site AZ U:9:97; (c) Feature 13, located in site AZ U:9:97; (d) Feature 14, located in site AZ U:9:97; (e) Feature 16, located in site AZ U:9:97; (f) Feature 53, located in site AZ U:9:128; (g) Feature 57, located in site AZ U:9:95. Shade patterns underneath diagrams show species relative abundance in pie charts (see text for details).

species, followed by *D. stevensoni* and minor emergences of *C. vidua*, *I. bradyi*, *H. reptans*, *C. patzcuaro* and *P. pustulosa*. Although the paleosalinity index was dominated by *L. staplini*, the influence of *D. stevensoni* was clear toward the end of the canal history. Samples in this canal belonged to Assemblage IV (*L. staplini*/*D. stevensoni*-dominated).

Within Feature 16 at AZ U:9:97 (ASM), *L. staplini* dominated the assemblages, accompanied by *C. vidua* and *D. stevensoni*, and the occasional occurrence of *C. patzcuaro*, *H. reptans* and *P. pustulosa* (Figure 3(e)). The paleosalinity index was controlled by *L. staplini*, yet *C. vidua* and to a lesser extent *D. stevensoni* influenced the curve's trend. Assemblage IV occurred at the bottom and top of the canal; Assemblage I characterized the middle portions of this sequence.

Six species were present in Feature 53 at AZ U:9:128 (ASM) (Figure 3(f)). *C. patzcuaro* and *L. staplini* were co-dominant, but closely associated with *C. vidua* and the uncommon appearance of *I. bradyi*, *H. reptans* and *D. stevensoni*. The paleosalinity index was dominated by *C. patzcuaro* but strongly affected by *L. staplini* and occasionally by *C. vidua*. Feature 53 was mainly characterized by Assemblage II (near-equivalent proportions of *L. staplini*, *C. patzcuaro* and *C. vidua*), although *C. vidua* was not as common in this canal as it was in others that occasionally evolved into Assemblage III (*C. patzcuaro*-dominated) or I (*L. staplini*-dominated).

Finally, six species occurred in Feature 57 at AZ U:9:95 (ASM) (Figure 3(g)). *C. patzcuaro* was the dominant species, although *L. staplini* and *H. reptans* were also common. *C. vidua*, *I. bradyi* and *P. pustulosa* were less abundant. *C. patzcuaro* dominated the paleosalinity index, but with clear influence of *L. staplini*. The entire sequence was characterized by Assemblage III (*C. patzcuaro*-dominated).

Interpretation

Episodes of water salination and freshening are shown by ostracode assemblages throughout the operational

(b)

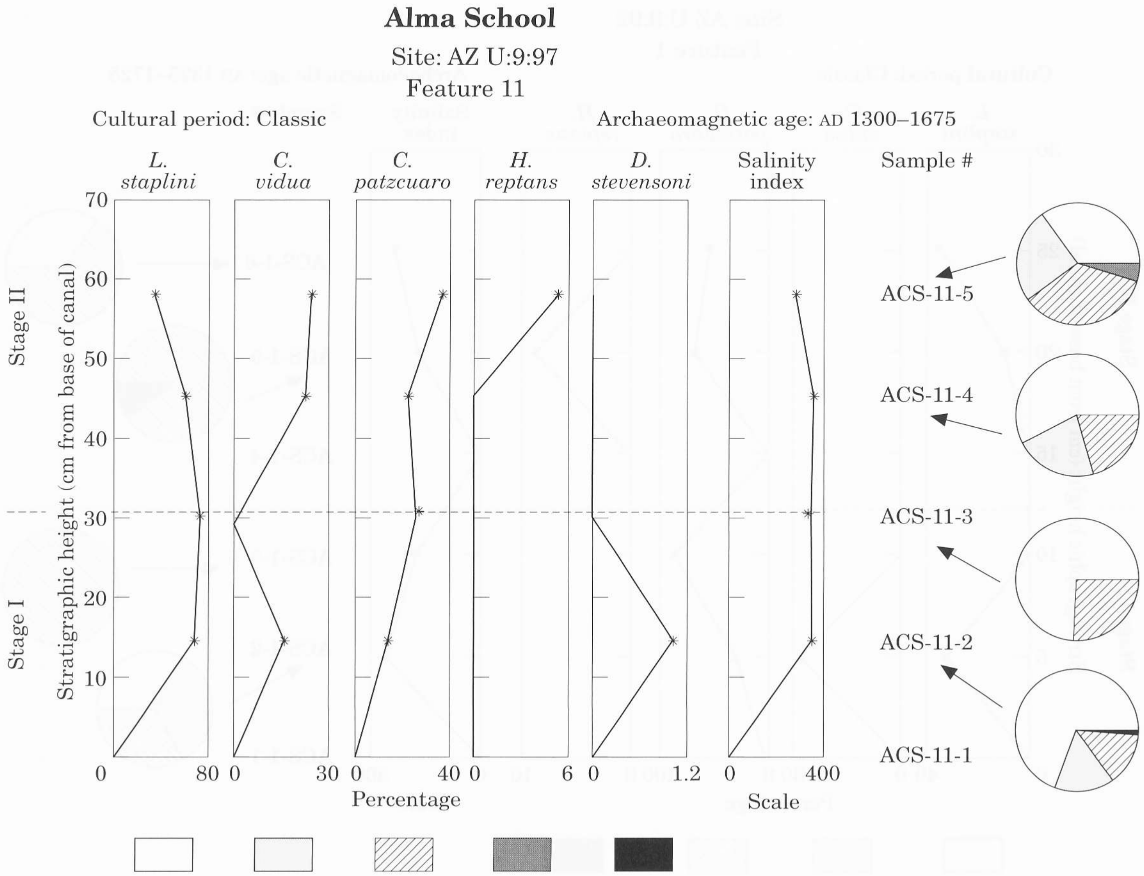


Figure 3. (b).

history of the canals. Based on the combined faunal (including ostracodes and other fossils that may be critical for canal history reconstruction) and sedimentological composition of the canals, a preliminary interpretation of the canals' history was constructed.

The six intervals sampled in Feature 1 evolved from gravel and coarse sands barren of fossils at the base of the canal to medium-fine sands and silts with a low diversity of ostracodes, a few fish vertebrae and molluscs at the top (Table 1). The ostracode content and the sedimentological composition suggested that Feature 1 was a small to medium-sized canal subject to long-time operation with moderately diluted water but suddenly abandoned. The history of Feature 1 offers two alternative interpretations. First, it operated as a lateral or small distribution canal through most of its history but at the end the canal was abandoned allowing halobiont fauna to survive until the desiccation of the canal. Second, it is possible that intervals ACS-1-5 and ACS-1-6 correspond to a natural flooding episode followed by gradual sediment settling and evaporation as shown by progressively finer sediments from the base upward and dominance of halobiont ostracodes.

In contrast, Feature 2 was represented by only one sample from gravelly coarse sands at the base of the canal, yet the monospecific occurrence of *L. staplini* and molluscs in a coarse sediment substrate suggested this canal was flooded for a short time, perhaps to divert water for other purposes in the course of agricultural activities. The rough substrate and the presence of *L. staplini* is unsettling because the former indicates a high-energy stream whereas the latter suggests still water bodies. Thus, the best possible interpretation of this canal is that after a sudden flooding of the canal, it was abandoned, allowing halobiont ostracodes to grow until the canal became desiccated. Fossil content suggested that Feature 2 was a lateral canal. Short life-cycle ostracodes, like *L. staplini*, are the only kind of organisms to adapt to ephemeral water bodies; furthermore, the monospecific characteristic of this canal strongly suggested relatively high salinity. Further analysis of stratigraphically higher samples within the canal would be necessary to render any definitive conclusions.

Similarly, Feature 10 was represented by only one sample at the base of the canal. The fine sand, silt and clay sedimentological composition suggested a distribution canal. The relatively high ostracode diversity and molluscs indicate moderately saline waters in a low-energy stream environment. Although the interval

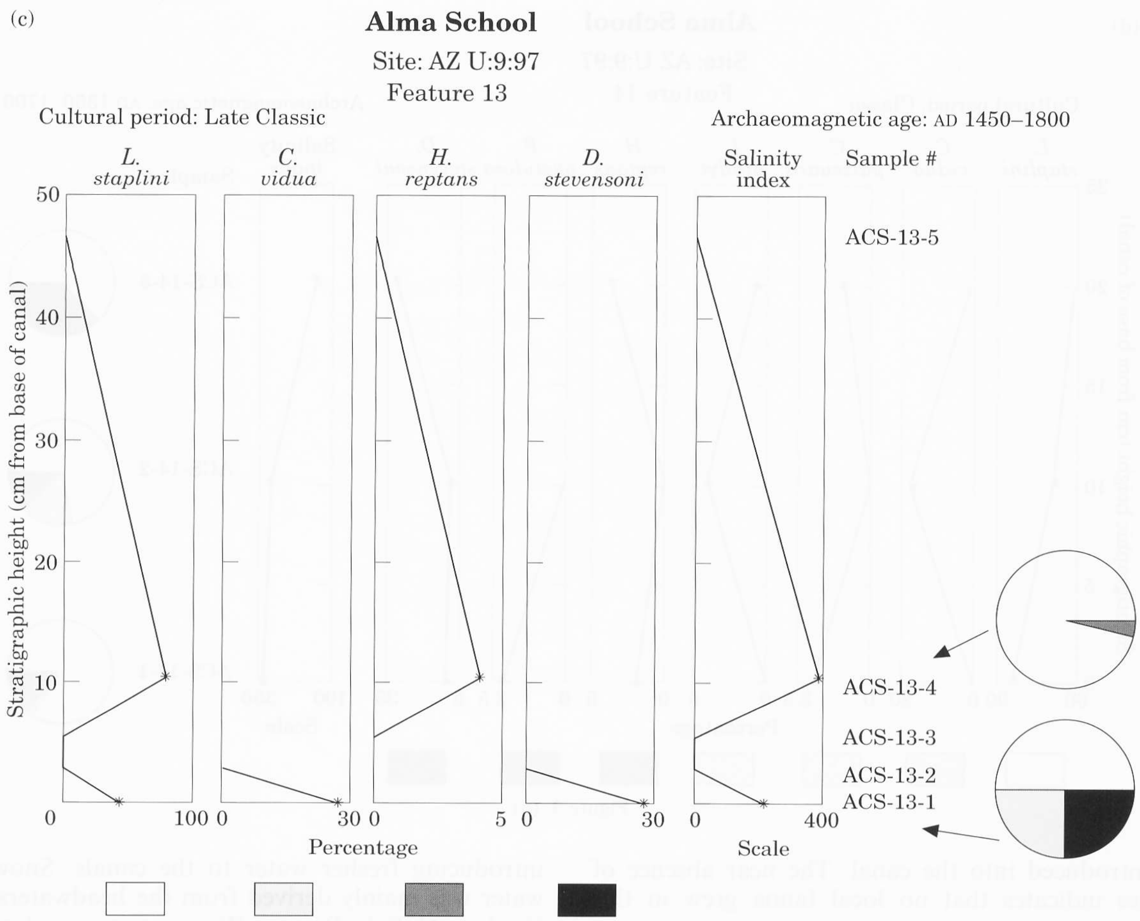


Figure 3. (c).

was dominated by *L. staplini*, the relatively high abundance of *C. patzcuaro* implied that this canal remained operational for a moderate length of time. Furthermore, the occurrence of *C. vidua*, *I. bradyi* and *H. reptans* also indicated that water remained moderately saline. However, further interpretation of this canal would require more sampling in a stratigraphic sequence.

The five intervals collected from Feature 11 consist of gravelly coarse/medium sand and silt most likely accumulated in a moderate-energy stream environment. The recognized ostracode assemblages were consistent with these conditions. The steady dominance of *L. staplini* indicated saline waters that evolved from moderate to moderately high salinity. However, toward the end of the record salinity dropped, as suggested by the increasing abundance of *C. patzcuaro* and *C. vidua*. The occurrence of *H. reptans* also indicated low salinity waters. The presence of *C. patzcuaro* implied that this canal remained under operation for a long time (>3 months). The occurrence of charophyte's oogonia (reproductive structures of calcareous algae indicative of permanent and alkaline waters) confirmed the moderate to long time operation hypothesis. Feature 11 probably was a distribution canal that suddenly received diluted water toward the end of the record. This dilute water event allowed some species not previously recorded to grow. The lack of further samples into the plough zone limited any analysis to determine if this sequence corresponds to headgate operation or natural flooding. Although the fact that water dilution is not as drastic as it would be under natural flood events, it is possible that this represents a human phenomenon.

The five intervals in Feature 13 consisted of gravelly coarse sands that graded only once in the record to medium/fine sands and silts (ACS-13-4). The poor fossil record consists of a few molluscs and ostracodes. The ostracodes suggested moderately saline and hypersaline conditions resulting from unrelated events. At the time of initial canal operation ostracode Assemblage IV, introduced to the system, survived in moderate salinity until the canal desiccated. Canal desiccation was most likely to have been as sudden an event as the flooding was, preventing ostracode fauna from gradually evolving to high salinity species. This criterion rests on the fact that neither *C. patzcuaro* nor *D. stevensoni* (long-term indicators) occurred or were important in this canal. The adult:juvenile ratios suggested that ostracodes deposited in these sediments

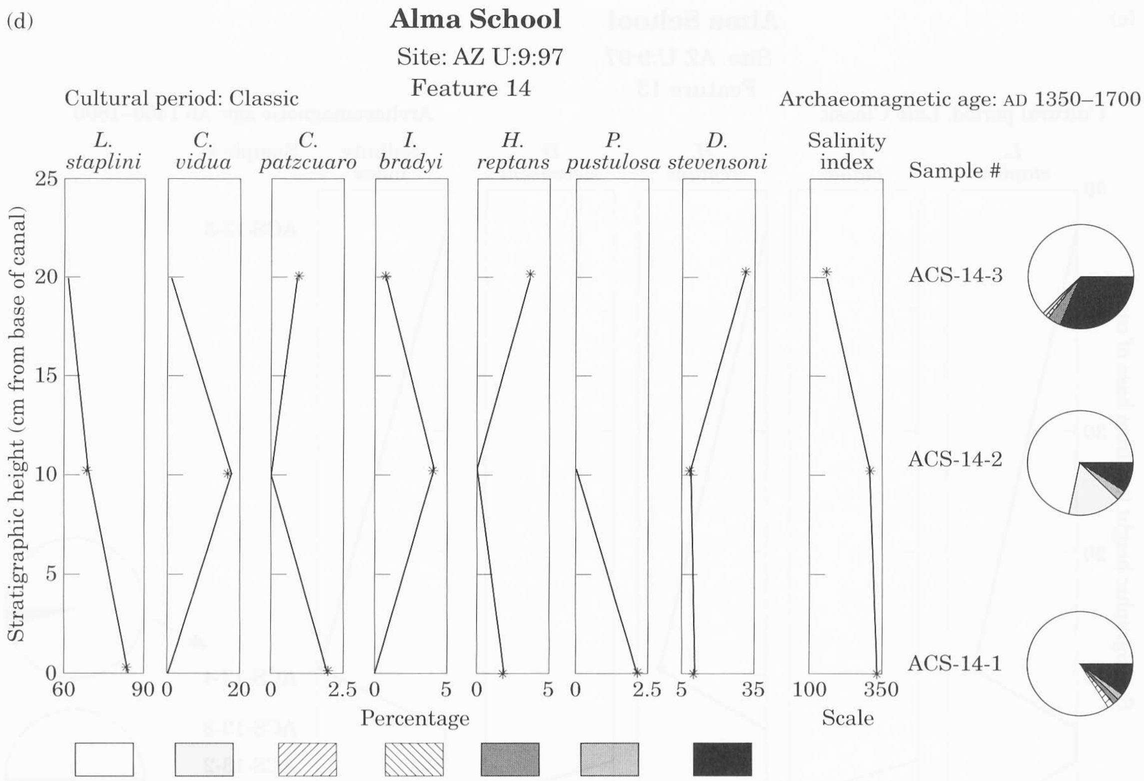


Figure 3. (d).

were introduced into the canal. The near absence of juveniles indicates that no local fauna grew in this canal.

This canal (Feature 13) remained inactive for a long time. It probably was never opened to agricultural activities again. However, in a later stage it was flooded and mostly *L. staplini* (Assemblage I) survived because of hypersaline conditions. The upward stratigraphically fining sediments from sample ACS-13-3 to ACS-13-4 were a good indication of natural flooding. The canal record ended with a dry stage, suggesting limited, if any, canal operation. Feature 13 probably was an "unsuccessful" distribution canal.

The three intervals sampled from Feature 14 graded from coarse/medium sand and silt to medium/fine sand and silt accumulated under a moderately low-energy stream. Molluscs and ostracodes were the only fossils present. Although *L. staplini* dominated the assemblage (IV) reported in this canal, it gradually decreased as others (*D. stevensoni* and *C. vidua*) increased in abundance. This paleoecological succession suggested decreasing salinity toward the end of the record. Thus, it is possible that Feature 14 was a minor distribution or lateral canal subject to periodic operations. The somewhat convoluted shape of canal strata and the variability of the faunal record implied that the intervals analysed probably reflect independent events through the season. Canal water freshening may be explained if we assume an agricultural cycle starting in the late winter as snow meltwater reached the area introducing fresher water to the canals. Snow meltwater was mainly derived from the headwaters of the Verde and Salt Rivers. We cannot speculate what paleoecological trend characterized this canal above sample ACS-14-3 because no stratigraphically higher samples from this feature were available from which to detect more information about its evolution.

Feature 16, composed of five intervals, mostly consisted of fine sands, silt and clay typical of low-energy streams. The fossil record included molluscs and ostracodes; the latter varied from Assemblage I to IV. Within Assemblage I, ostracodes suggested saline waters gradually decreasing to moderate conditions. The change from Assemblage I to IV was only indicated by the significant increase of *D. stevensoni*. This may have resulted from long-term canal operation since perennial water bodies allow *D. stevensoni* to complete its life cycle (usually >3 months). This species has been previously associated with human activity in Hohokam irrigation canals (Palacios-Fest, 1994*a*), and in other human-disturbed areas in Africa (Cohen, pers. comm., 1993). Furthermore, canal water freshening may have been associated with freshwater input late in the canal history. Feature 16 probably functioned as a lateral canal. Uniform sediment grain size in this feature suggested continuous flow due to human activity. No evidence of natural flooding was recorded.

Only one sample was taken from Feature 20. It consisted of gravely coarse sand and silt. Sediment size suggested deposition in a moderately high-energy

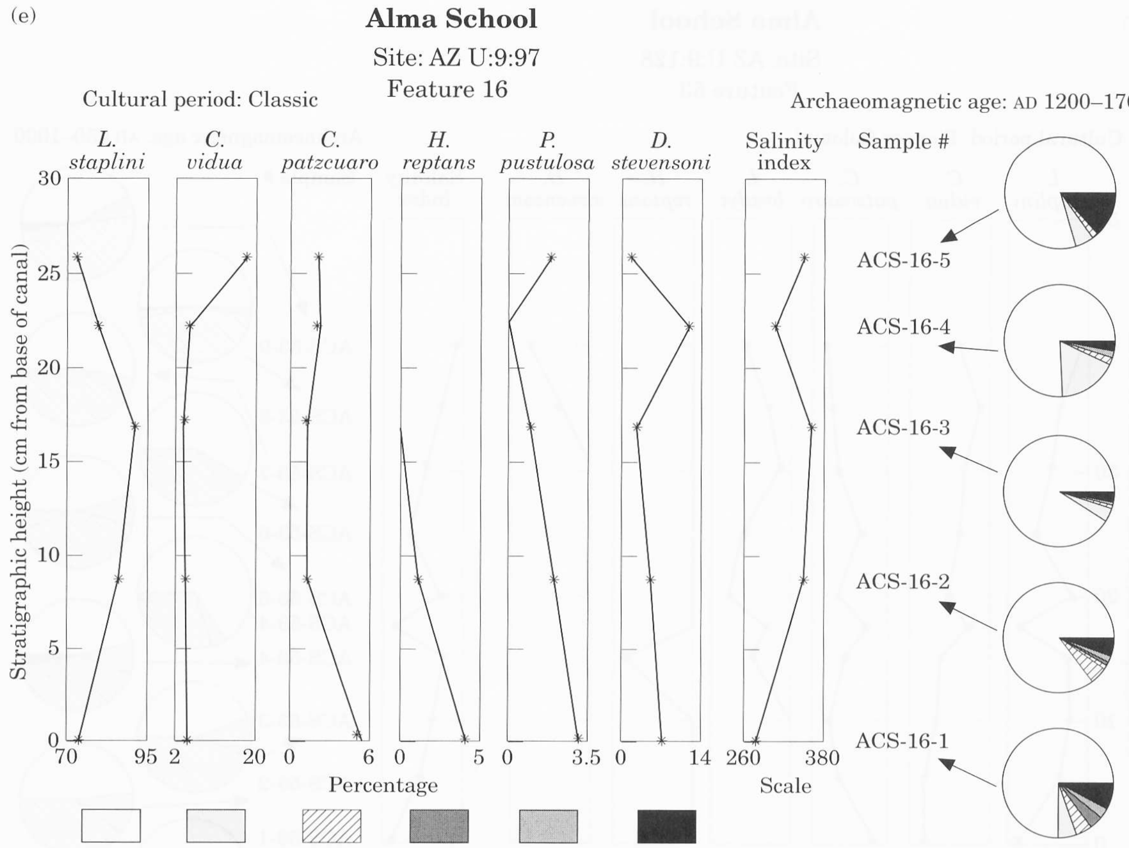


Figure 3. (e).

stream environment. Molluscs and ostracodes occurred in this canal. Ostracode Assemblage III (*C. patzcuaro*-dominated), characterized by the *L. staplini* abundance, strongly indicated moderately saline waters. A lack of ostracode record above the canal base (sample ACS-20-1) limited any interpretation of the canal history. Canal dimensions, grain size and ostracode fauna suggested that it was a distribution canal active for more than 3 months.

Feature 53 consisted of nine strata, with gravelly coarse sand and silt at the base. Above this, fine sand, silt and clay accumulated to the top. These sedimentological attributes indicated that once the canal was flooded (quite suddenly), prolonged, low-energy flow characterized this feature. The fossil record consisted of ostracodes, molluscs, charophytes and testate amoebae*. Ostracodes and the appearance of charophytes suggested a long period of activity in this canal. Ostracodes were mainly Assemblage II (near-equivalent proportions of *L. staplini*, *C. patzcuaro* and *C. vidua*). However, ACS-53-1, ACS-53-4′ and ACS-53-6 were characteristic of Assemblage I (*L. staplini*-dominated) and ACS-53-9 was Assemblage III (*C. patzcuaro*-dominated). These fluctuations were significant because this was the first and only canal in which such variation was recorded. Feature 53 was probably a distribution or main canal that operated for a long time, subject to episodic evaporation and dilution of water.

Feature 57, composed of six intervals, consisted of fine sand, silt and clay at the base of the canal, overlaid by silty clay rich in pyrite nodules (Table 1). It contained ostracodes, molluscs and charophytes. The grain size and the fossils suggested a long-term, low-salinity and low-energy stream environment. The ostracode Assemblage III (*C. patzcuaro*-dominated) remained homogeneous throughout the canal history, however, some significant fluctuations of *L. staplini* showed a strong influence of salinity. This canal remained moderately saline through most of the record, with two exceptions. First, ACS-57-3 suggested an evaporative episode immediately followed by a drastic dilution or dilute water input (ACS-57-4). After this freshwater episode the canal regained its moderate salinity. Second, authigenic pyrite nodules indicated anoxic conditions below the surface sediments (0·5–1·0 cm) characteristic of standing or slow-motion bodies of water. Therefore, Feature 57 probably was a distribution or main canal that operated for a long time with slow but constant streamflow.

*Testate amoebae are reported here for the first time in irrigation canals. Their occurrence and preservation are only possible under gentle water flows since these organisms agglutinate fine sediments around their soft body walls.

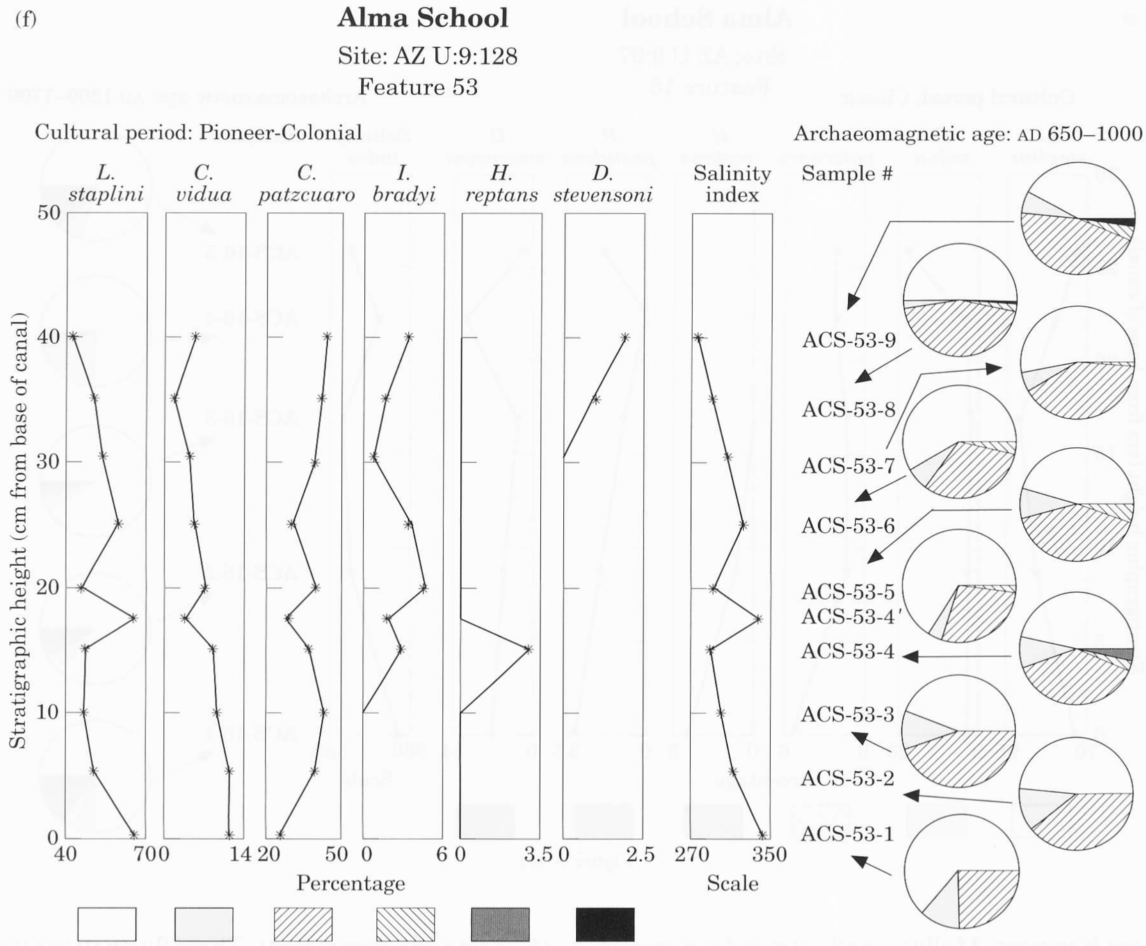


Figure 3. (f).

Ostracode Dynamics in Pueblo Blanco Canals

The data presented here were the first ostracode assemblages from canals dating almost exclusively from the Classic Period. Based on the ostracode record, a variety of sequences was recognized which allow us to distinguish main from distribution and lateral canals. In addition, canal water pathways were inferred from the faunal content (assemblage replacement). As established earlier, canal waters evolved from type I to type II of Eugster & Hardie's (1978) pathway model. Pathway variation was more significant as water in-flow entered smaller and more distant canals, progressing from main to distribution to lateral canals.

Based on the ostracode record, two main, five distribution, and three lateral canals were identified. If all these canals were contemporaneous, the ostracode record suggested a salination of distal agricultural fields. Evidence of natural flooding was limited to two features (1 & 13). Dilute water input into the canals at the time of these floods probably resulted from late winter snow melt up-stream in the Verde and Salt Rivers, or from large local storms. The lack of evidence of flooding only allows one to make a qualitative analysis of the ostracode record. Thus, the ostracode record suggested the hypothesis that human canal operations were influencing land salination. While salt build-up may not be evident in the geological record, ostracode assemblages are good indicators of progressive salination.

Conclusions

The Pueblo Blanco canals, as part of the Sawik Irrigation System, provide important paleoecological information for understanding the human–environment relationship in south-western North America. Ostracode paleoecology of Pueblo Blanco canals showed a well-defined pattern of canal water salination and dilution. Progressive salination of canal waters resulted from gradual evaporation after the initial inflow to the canals. These trends allow us to estimate seasonal agricultural irrigation cycles during the Classic Period.

Variations in ostracode assemblages showed significant changes from sample to sample within individual canals and allowed reconstruction of canal operation.

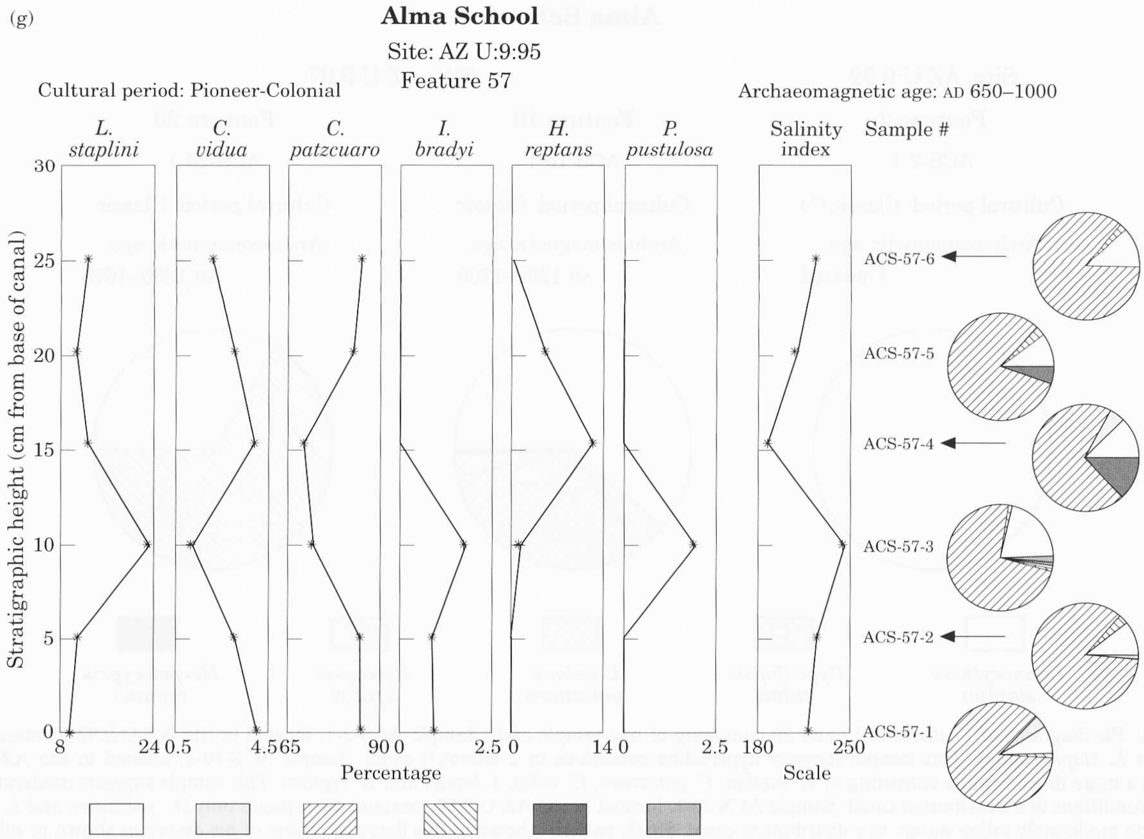


Figure 3. (g).

Changes in water chemistry were also inferred from ostracode assemblages. The resulting patterns appeared to be of anthropogenical origin rather than climatic for two reasons. First, they occur in a relatively short time, if it can be assumed that the canal strata represent the last irrigation cycle for the particular canal. Second, they consistently showed at least two evaporitical cycles that suggested different episodes of canal operation (e.g. Features 1 & 11).

Two probable pre-Classic or mixed period features (53 & 57) also showed evidence of anthropogenic disturbance. However, in these canals such evidence was subtler, probably because of sustained input and use of fresher water in the course of canal operations (Palacios-Fest, 1994*a*: 21–22). In Feature 53, ostracode assemblages fluctuated from saline to freshwater to hypersaline, all in a short period, then to fresher water conditions. Although this pattern may have represented a natural cycle, it is plausible that the canal was operated mostly in the late winter to early summer (before summer monsoon). Thus, water salination may have resulted from a combination of decreasing water input from human manipulation and overall climatic increase in temperature. Geochemical (ostracode shell chemistry) evidence of such patterns was recorded from modern canals in Magdalena, Sonora, Mexico, and prehistoric canals around Las Acequias in Tempe, Arizona (Palacios-Fest, unpublished data; 1994*b*).

Features 1, 11, 14 & 16 showed evidence of water dilution at one or several stages. The occurrence and steady increase of *Darwinula stevensoni* in Features 14 & 16 appeared to be a response to anthropogenic disturbance. Occurrence of this species in other features was random and of little significance. Features 2, 14 & 16 suggested increasing salination of irrigation canals that may be related to intensive land use in the Classic Period.

The greatest significance of salination and dilution patterns observed in the Pueblo Blanco canals was that for the first time it was possible to associate them with anthropogenical activities, rather than climate. For example, dilution events may have resulted from seasonal (early spring) Salt River streamflow when the Hohokam initiated irrigation activities. Salination episodes derived from sluggish flow conditions after initial canal operation; these were not necessarily seasonally driven but related to subsequent evaporative events caused by reduced water input and high evaporation. In any event, the anthropogenical signature appeared to be the primary factor affecting ostracode assemblages in the Pueblo Blanco canals. Detailed stratigraphic control of canal strata was determinant to reach the present conclusions. However, further studies including ostracode shell chemistry are encouraged to establish temperature and salinity patterns for Hohokam irrigation systems.

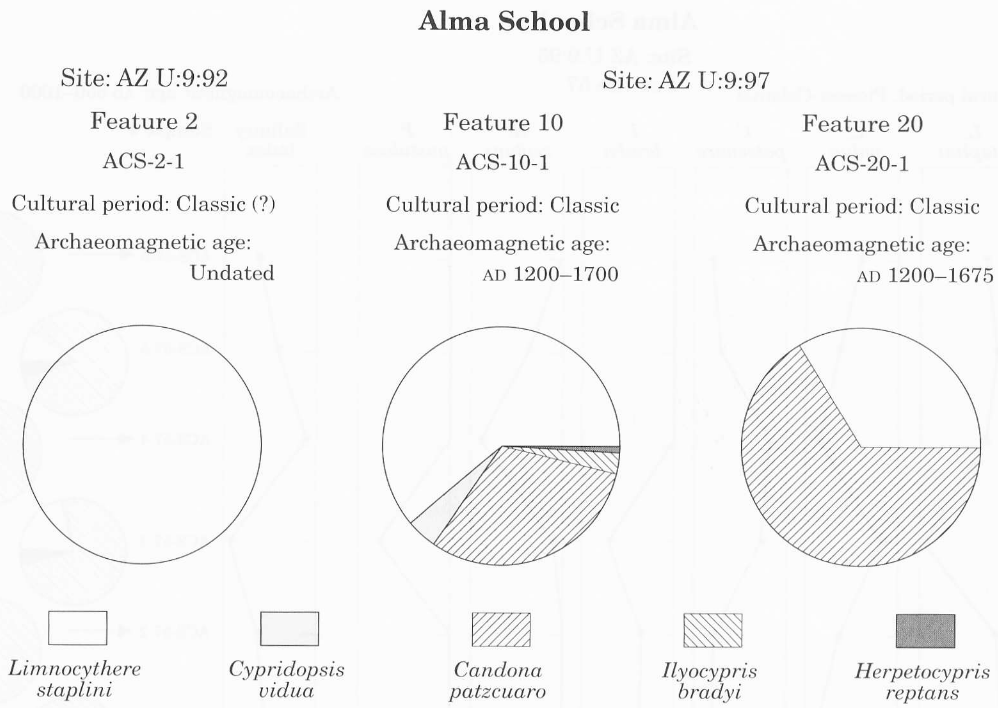


Figure 4. Pie diagrams of Features 2, 10 and 20 consisting of one sample each. Sample ACS-2-1, located in site AZ U:9:92, is monospecific (contains *L. staplini* only). This sample suggests hypersaline conditions in a lateral(?) canal. Sample ACS-10-1, located in site AZ U:9:97, contains a more diverse fauna consisting of *L. staplini*, *C. patzcuaro*, *C. vidua*, *I. bradyi* and *H. reptans*. This sample suggests moderately high salinity conditions in a distribution canal. Sample ACS-20-1, located in site AZ U:9:97, contains two species only (*C. patzcuaro* and *L. staplini*) suggesting moderately saline waters in a distribution canal. Shade patterns shown in this figure are those of pie diagrams shown in subsequent figures (see text for details).

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