Las Capas: Early Irrigation and Sedentism in a Southwestern Floodplain

DRAFT REPORT

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CANAL ENVIRONMENTS

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The geomorphology, stratigraphy, and sedimentology of Las Capas, AZ AA:12:111 (ASM), indicates rapid alluvial aggradation from seasonal overbank floods and a few larger flood events throughout the time of agricultural occupation between approximately 2100 B.C. and 500 B.C. (see Chapter 2, this volume). They also indicate rapid sedimentation in the canals, requiring constant cleaning and repeated rebuilding throughout the time of canal irrigation between about 1250 B.C. and 500 B.C. (see Chapter 7, this volume). Some important questions remain, however, about the environmental conditions of the floodplain setting and the canals. How high was the water table? What was the vegetation like along the canals, in the fields, and in the floodplain around the settlement? What were the seasons, frequencies, and durations of canal flows? Was water diverted from the river only during ephemeral flood flows, or was the water source a groundwater-fed perennial flow? Through the sequence of canals, were there any changes in the local vegetation and in canal flows and modes of operation?

These questions are addressed in this chapter through analyses and interpretations of two biological traces of Las Capas canal environments that are preserved in sediments: fossil pollen and the shells of microscopic crustaceans called ostracodes. With reference to these proxy indicators, paleoclimatic conditions are inferred; the water table fluctuations and the vegetations of the floodplain, the canals, and the adjacent fields are reconstructed; and changes in canal flows and modes of operation are traced through the sequence of canals.

As in other chapters of this volume, the set of canals at Las Capas are referred to by their site number, AZ AA:12:753 (ASM). Individual canals are referred to by their feature numbers as Canal 1, Canal 2, and so forth. The canal numbers do not represent their order in the canal sequence. Figure 8.1 illustrates the canal sequence in relation to floodplain strata and their radiocarbon-dated timespans. Trench locations are shown in Figure 8.2.

PALYNOLOGY

Several palynological studies of Late Quaternary sediments have been conducted in the Tucson Basin and in surrounding southern Arizona (see references in Davis 1994). Among modern pollen samples, those from the Santa Cruz (and other) floodplain are dominated by the Chenopodiaceae/*Amaranthus* pollen type, while samples from the uplands are dominated by the *Ambrosia* pollen type (Davis 1994; Hevly et al. 1965).

Pollen analysis of samples from prehistoric archeological sites in the Tucson Basin and vicinity are dominated by various shrub and herb types. The Chenopodiaceae/*Amaranthus* pollen type often exceeds 70 percent of the pollen assemblage. Other important types include the bursage (*Ambrosia*) and sunflower family (other Compositae/Asteraceae) pollen types. Maize (*Zea mays*) percentages generally are low (0-5 percent). The pollen of weeds (e.g., spiderling [*Boerhaavia*], globe mallow [*Sphaeralcea*], and *Tidestromia*) may exceed 50 percent in prehistoric fields (Fish 1985).

At open-air archaeological sites in the Tucson Basin, pollen preservation is often poor (over 25 percent deteriorated) and the concentration low (less than 5,000 grains/cm³). Relatively active geomorphological processes and alternately wet and dry conditions result in particularly poor pollen preservation at sites in floodplain settings. At the Santa Cruz Bend, AZ AA:12:746 (ASM), Stone Pipe, AZ BB:13:425 (ASM), and Square Hearth, AZ AA:12:745 (ASM), sites in the Santa Cruz floodplain, more than 75 percent of samples collected from cultural features had no pollen (Fish 1998; Van de Water 1998).

A previous palynological study at the nearby Costello-King site, AZ AA:12:503 (ASM)—less than 1 km northwest of AA:12:753 and of a similar age—revealed high percentages (up to 10 percent) of maize pollen in certain samples (Davis 1998). Sediment samples from canals and artifact washes were analyzed. The pollen concentration was low (less than 4,000 grains/cm³), and Chenopodiaceae/*Amaranthus* pollen was the most abundant type (up to 97 percent). Other Compositae/Asteraceae pollen varied from 1-30 percent, and *Ambrosia* pollen varied from 1 percent to 17 percent. Maize pollen was present in one artifact wash and three sediment samples.

Sample Contexts

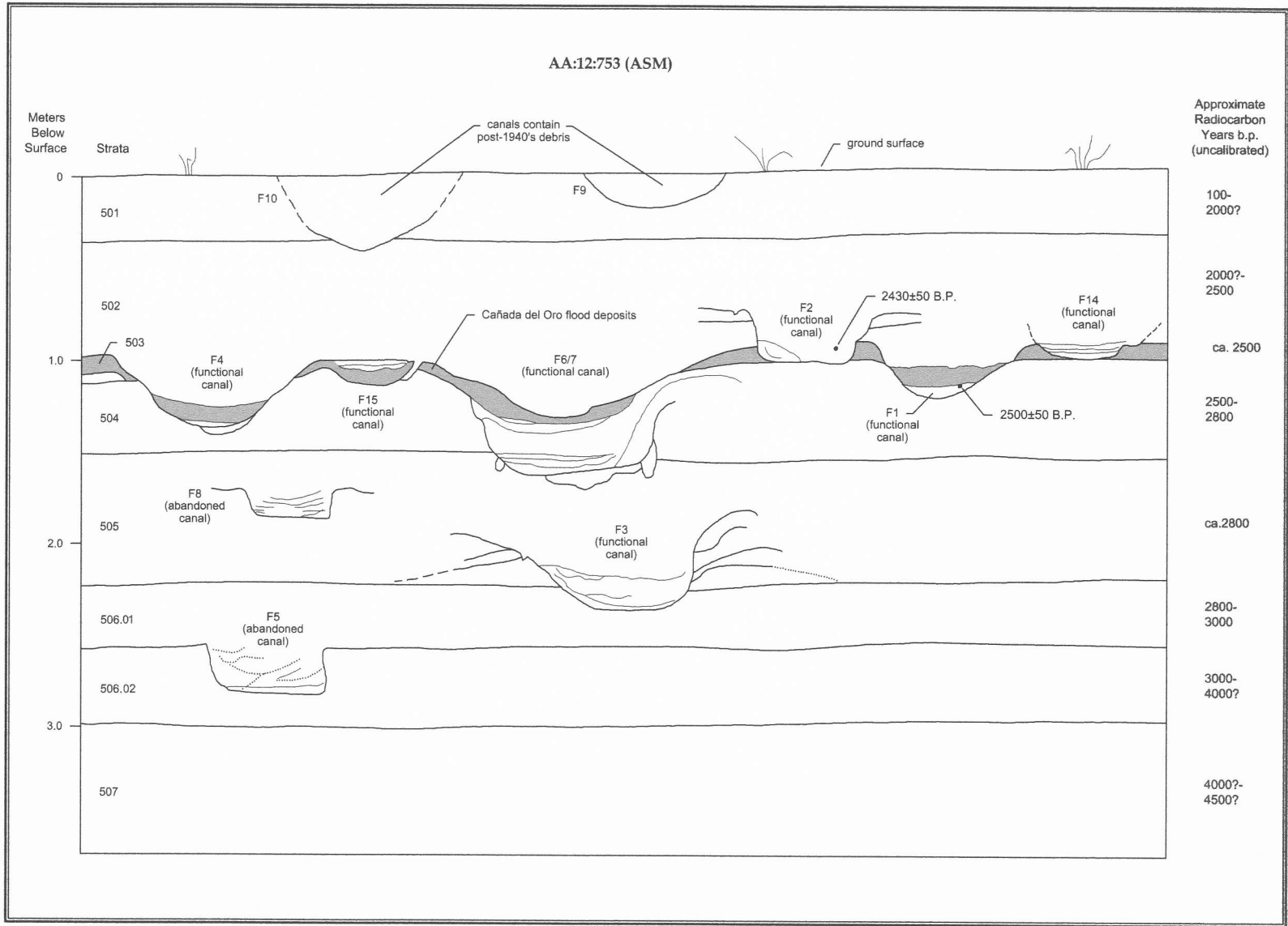Sixteen samples from Canals 3 and 4 at AA:12: 753—used during portions of the intervals bracketed

Figure 8.1. Composite diagram showing stratigraphic contexts and ages of canals at AZ AA:12:753 (ASM).
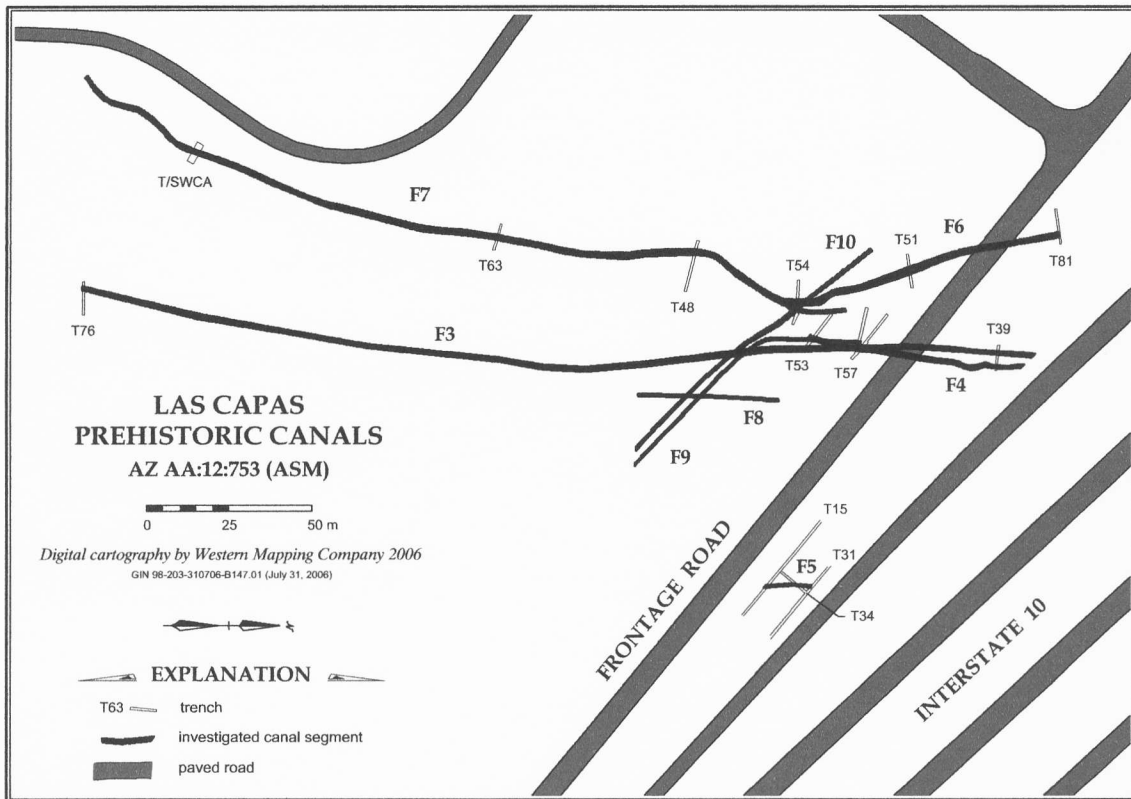
Figure 8.2. Trench locations for pollen and ostracode samples.

between about 1250-950 B.C. and 950-800 B.C., respectively (see Chapters 1 and 3, this volume) — were analyzed for the presence of fossil pollen. Five samples were collected from the oldest canal, Canal 3, including: one from the soil surface into which the canal was dug, three from canal-flow sediments, and one from the flood deposit which filled the canal and ended its use-life. The younger Canal 4 was sampled at two locations: one from a column above the Canal 3 samples (Trench 57) and the other from a cross section approximately 100 m downstream (Trench 46). The first set of samples (Trench 57) included three canal-flow samples and one sample from a related soil surface. The second set (Trench 46) included three canal-flow samples, four samples of spoil from canal excavation or clean-out related to canal maintenance, and one sample from a related soil surface — probably a field irrigated by the canal.

Methods

Pollen was extracted from the sediment samples by routine acid digestion (Table 8.1). One *Lycopodium* tablet (13,911 spores) was added to each sample (volume 5 cm³) to aid in the calculation of pollen concentration. A total of 300 grains of the pollen of upland plants were counted per sample. Pollen of aquatic plants, spores of ferns and fungi, algae, charcoal, and other microfossils are not included in the sum. Pollen clumps (aggregates) were counted as four grains and were not recorded separately. The pollen sum of 300 upland grains was the divisor for determining the percentages of all pollen types, spores, charcoal, and other microfossils. The pollen concentration was calculated for the pollen sum. It is an index of preservation and the sediment accumulation rate. Low concentration, combined with poor preservation, may indicate loss of pollen, making interpretation of the pollen assemblage questionable. Alternatively, good preservation and low concentration might be the result of rapid sediment accumulation.

Results and Interpretation

The pollen preservation is relatively good (2-32 percent deteriorated beyond the possibility of identification), but the pollen concentration is variable

Table 8.1. Pollen extraction procedure.

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(1) Add 1 *Lycopodium* tablet (batch #710961; 13,911 grains/tablet)

(2) Swirl solution, let stand 15-20 seconds, and screen (180 micron mesh, stainless steel) into 50 ml test tubes, rinse, add 10 ml 10 percent HCl

(3) Add 10 ml concentrated HCl, mix, add 30 ml H_2O, mix; centrifuge, decant, water rinse

(4) Add 40 ml HF overnight or 1 hour in boiling water bath; centrifuge, decant, water rinse; transfer to 15 ml glass tubes

(5) Acetolysis[a]; centrifuge, decant, water rinse

(6) Add 10 ml 10 percent KOH 2 minutes boiling water bath; centrifuge, decant, water rinse with hot water until clear

(7) Stain with safranin "O"

(8) Transfer to labeled 1 dram shell vials

(9) Add a few drops of glycerin

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[a]Acetolysis

  (a) 5 ml glacial acetic acid centrifuge and decant

  (b) Stir sample, add 5 ml acetic anhydride (volumetric dispenser)

  (c) Add 0.55 ml H_2SO_4 to acetic anhydride solution (volumetric pipet), mix, centrifuge, decant into glacial acetic acid

  (d) 5 ml glacial acetic acid centrifuge and decant

(790-49,000 grains/cc) in the AA:12:753 samples (Table 8.2). Thirty pollen types and six spore types were identified, as were three miscellaneous microfossils. Chenopodiaceae/*Amaranthus* pollen is the most abundant type (up to 90 percent). Pollen of Compositae/Asteraceae such as ragweed (*Ambrosia*), is also relatively abundant (up to 25 percent and 7 percent, respectively) in the canal-flow sediments of Canal 4 and in the flood deposit that ended its use-life (Stratum 503; see Chapter 7).

The pollen spectra preserved in the older and younger canals are generally similar, although the sampled canal-flow sediments in the older Canal 3 have higher percentages of Chenopodiaceae/*Amaranthus* pollen and lower percentages of charcoal than do the canal-flow sediments sampled in Canal 4 (Figures 8.3-8.4; see Table 8.1). The bottoms and banks of both canals apparently supported higher densities of weeds than the agricultural fields did. The canal-flow samples from both exposures (Trenches 57 and 46) of Canal 3 average 5.1 percent *Ambrosia* and 20.5 percent other Compositae/Asteraceae. This is as compared to 1.5 percent *Ambrosia* and 5.1 percent other Compositae/Asteraceae in the samples from the related soil. The sample from the soil related to Canal 4 is similar to those of the soil related to Canal 3, with 1.0 percent *Ambrosia* and 7.6 percent other Compositae/Asteraceae.

The sample from a flood deposit in Canal 3 is palynologically similar to the canal-flow samples from this feature, as would be expected if water transport was responsible for both contexts (see Figure 8.4 and Table 8.1). The flood deposit also has very high percentages of charcoal, as do the canal-flow samples. These similarities are consistent with brief periods of deposition of the canal-flow sediments. The percentages in the clean-out and over-bank samples of Canal 4, Trench 46, are intermediate

between the soil and canal-flow samples. They may contain a mixture of pollen transported regionally by river flow and local pollen from canal erosion of the local soil.

The percentages of the pollen of wet-ground plants (Cyperaceae, *Alnus, Fraxinus, Juglans, Populus,* and *Salix*) are low (<2 percent) in all contexts, and there are no consistent differences between the canal-flow samples and soil samples (see Figure 8.4; see Table 8.1). This indicates a non-waterlogged floodplain surface in the vicinity of the canals—despite the presence of a marshy cienega soil nearby during the time of Canal 4 (see Chapter 2)—because the pollen percentages of wet-ground plants in contemporary Southwestern wetlands typically exceed the percentages of upland plants (Davis 1994). However, the ostracode record indicates fluctuating water table levels during formation of the cienega soil (see below).

The abundance of *Ambrosia* and other Asteraceae probably results from transport of these grains from beyond the local floodplain. If the high percentages of Chenopodiaceae/*Amaranthus* pollen in the soil reflect local rather than regional vegetation, the floodplain in the vicinity of Las Capas was dominated by weedy annuals that prefer disturbed soils on active floodplains and the edges of cultivated fields and canals. The surrounding uplands would have been dominated by perennial shrubs such as bursage and other members of the sunflower family—as is the case today. There is no evidence for major differences from current climatic conditions.

The low values of wet-ground plants in all the canal samples suggest the canals did not retain water long enough to permit the growth of wet-ground vegetation in, or near, the canals. However, some of the canal-flow samples have spores of aquatic algae (*Spirogyra* and *Pseudoschizea*), indicating some intervals

Table 8.2. Pollen counts for sediment samples from AZ AA:12:753 (ASM).

Sequence	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
FN	56	55	60	59	58	57	54	97	148	107	6,600	89	103	154	110	6,604
Sum	304	304	304	303	304	302	302	304	301	301	304	302	308	306	306	304
Tracers	506	272	79	159	82	17	69	401	1,133	529	181	82	24	45	52	73
Conc gr/cc	1,672	3,110	10,706	5,302	10,314	49,425	12,177	2,109	739	1,583	4,673	10,247	35,705	18,919	16,372	11,586
Deteriorated	32	42	14	47	64	34	23	38	96	47	22	39	14	23	6	20
Cupressaceae	–	–	–	–	–	–	–	–	–	–	–	–	1	–	1	–
Pinus total	3	8	–	6	1	–	–	3	5	23	3	21	5	1	2	3
Populus	2	–	–	1	1	6	–	–	–	–	–	–	–	–	5	–
Quercus	2	3	1	–	–	1	–	4	9	3	–	2	–	–	1	–
Ephedra	3	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Larrea	1	5	2	2	2	1	–	6	3	1	–	1	–	–	–	–
Opuntia	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	3
Rhus	–	–	–	–	1	–	–	–	–	1	–	–	–	–	–	1
Zizyphus	1	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–
Ambrosia	13	21	6	4	1	1	7	14	10	20	2	13	6	6	5	3
Artemisia	1	1	–	–	2	–	–	1	1	1	–	–	1	1	–	–
Liguliflorae	2	–	–	3	1	1	–	4	6	4	–	–	–	1	–	1
Other Asteraceae	57	58	12	49	16	9	13	62	77	56	18	34	9	29	10	23
Chenopodiaceae/Amaranthus	175	162	257	184	211	253	259	160	77	129	245	187	266	237	276	248
Gramineae	9	1	6	5	1	–	–	7	5	4	1	–	–	5	1	–
Boerhaavia	1	2	3	–	3	–	–	1	8	7	6	1	–	–	–	1
Cruciferae	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–
Eriogonum	–	–	1	–	–	1	–	–	–	3	1	1	1	–	–	–
Erodium	–	–	–	–	–	–	–	–	1	–	–	1	–	–	–	–
Euphorbia	1	–	1	–	–	–	–	2	–	–	2	–	–	–	–	–
Kallstroemia	1	–	–	1	–	–	–	–	–	1	–	–	–	–	–	–
Malva	–	–	–	–	–	–	–	–	–	1	1	–	–	–	–	–
Sphaeralcea	2	1	–	2	–	1	–	2	2	–	2	1	1	3	–	–
Zea	–	–	1	–	1	–	–	–	–	–	–	–	4	–	4	1
Cyperaceae	4	1	1	–	1	1	–	–	1	1	8	6	7	–	8	–
Alnus	–	–	–	–	–	–	–	2	–	–	–	–	–	–	–	–
Fraxinus	1	1	–	2	–	–	–	–	1	2	–	–	–	–	–	–

Table 8.2. Continued.

| Sequence	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Juglans	–	–	–	–	–	–	–	–	–	2	–	–	–	–	–	–
Salix	2	1	–	–	–	–	–	–	–	–	1	–	–	–	–	–
Fern Spore	1	3	–	–	–	1	–	–	1	6	–	1	2	–	–	–
Selaginella	4	2	–	–	1	–	–	1	–	3	1	4	1	1	3	4
Pseudoschizea	1	1	–	–	–	–	–	1	4	2	–	–	1	–	–	–
Spirogyra	–	1	–	–	–	–	–	–	32	–	–	3	–	–	–	–
Thecaphora	1	3	3	–	–	1	1	3	1	9	7	13	4	2	10	11
Fungal Lg Clear	–	–	–	–	–	–	–	–	1	–	62	–	–	–	–	–
Fungal Spores	176	467	11	111	162	22	41	7	169	79	53	30	17	93	57	71
Arthropod Feces	7	9	5	9	2	2	3	4	28	41	20	38	4	1	17	4
Charcoal	4,102	5,964	1,283	4,341	4,165	1,708	958	4,377	3,083	4,703	1,576	6,997	1,362	1,169	1,045	3,563
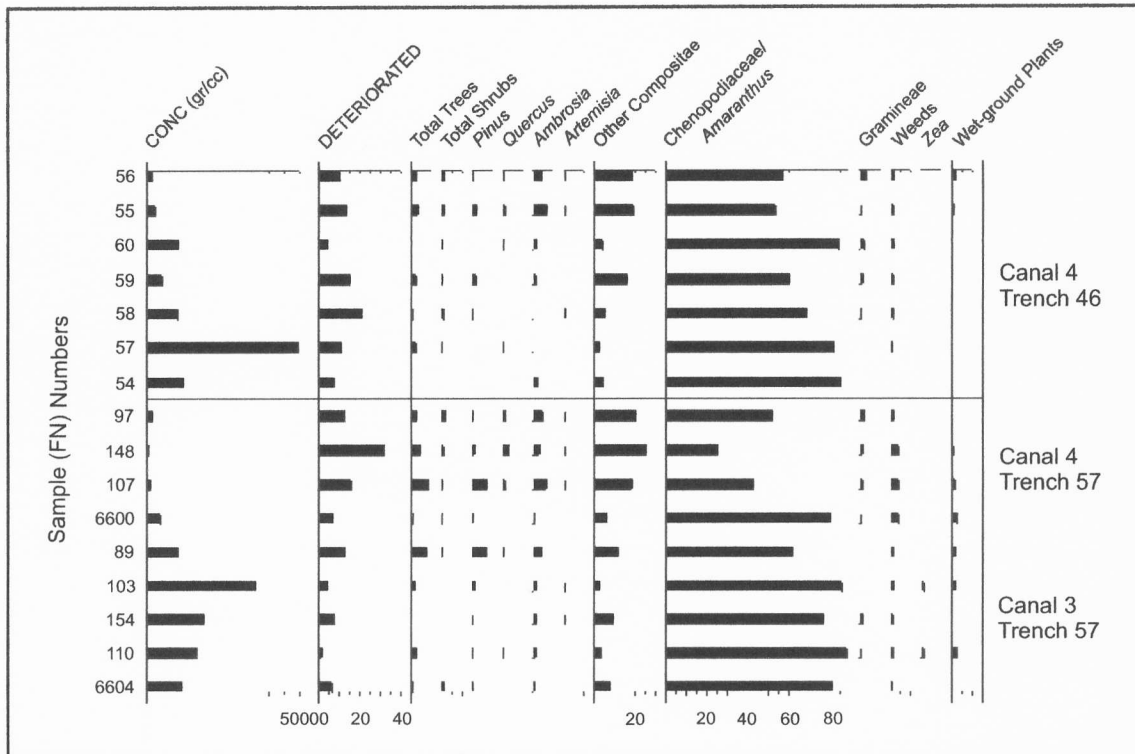
Figure 8.3. Percentage pollen diagram for abundant pollen types in AZ AA:12:753 (ASM) canal samples.
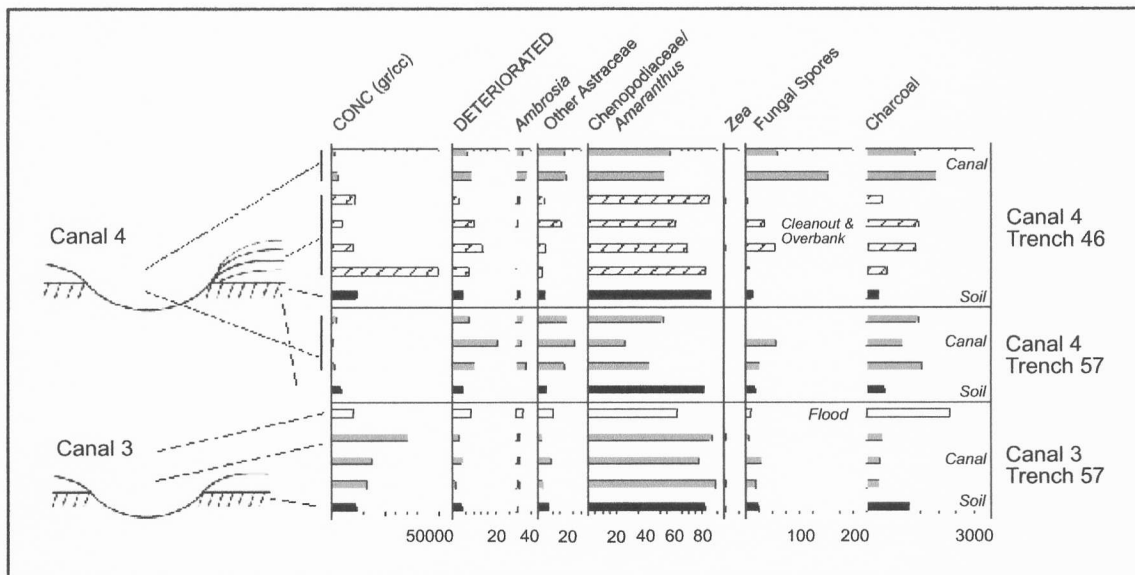

Figure 8.4. Summary pollen diagram (percentages of pollen sum, or concentration) for AZ AA:12:753 (ASM), showing contexts of samples from Canal 4 (younger) and Canal 3 (older canal). (Black bars indicate soils; gray bars indicate canal-flow sediments; hatched bars indicate overbank or clean-out sediments; open bars indicate over-topping flood.)

of water flow. The lower values of *Ambrosia* and other Asteraceae pollen in Canal 3 (see Figures 8.3-8.4; see Table 8.1) likely result from reduced contribution of pollen by water transport; that is, less frequent and shorter durations of water flow than during the use of Canal 4. Together, these patterns support a model

of episodic-to-cyclical intervals of stream transport of the sediments and the pollen they contain, as indicated in the sedimentologies and stratigraphies of the canals (see Chapter 7), as well as by the paleoecologies of ostracode populations (see below).

Evidence for agriculture is clear. Maize (*Zea mays*) pollen is present in low levels (<2 percent) in three samples from Canal 3 and in two samples from Canal 4 (Figure 8.5; see also Figures 8.3-8.4; see Table 8.1). However, the extent of the agricultural modification of the floodplain may not have been great during the time of canal use at this site, because the percentages of weed pollen in the canals are low (<2 percent in most samples), compared with the usually high values (over 50 percent) found in Hohokam canals from the later prehistory of southern Arizona (Fish 1985).

The palynology of AA:12:753 is very similar to that of the nearby and approximately contemporaneous Costello-King site (Davis 1998). However, the samples from AA:12:753 have higher pollen concentrations and lower percentages of weed and maize pollen, suggesting lesser disturbance. The exact temporal relationship between the two sites is unclear; therefore site use intensity may have differed either in space or time.

OSTRACODE PALEOECOLOGY AND TAPHONOMY

Ostracodes have been used previously to reconstruct the history of operation of prehistoric canal systems in the Phoenix Basin (Palacios-Fest 1989, 1994, 1997). Prior to these studies, Bradbury et al. (1990) used nonmarine ostracodes as indicators of agricultural activity by the Maya in Belize. Other studies have also shown the relationship between ostracodes and prehistoric agricultural activities (Curtis et al. 1995; Goman and Byrne 1998). However, these latter studies relate ostracodes from lake deposits with pollen grains of cultigens to infer environmental changes. None of these studies established a direct connection between canal operation and ostracode populations. This section expands upon a preliminary report on the ostracode record of the Las Capas canals (Palacios-Fest et al. 2001).
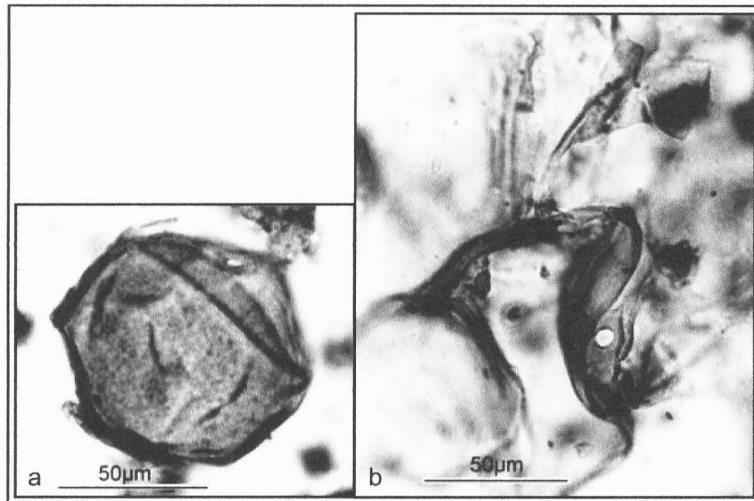

Figure 8.5. Photographs of maize (*Zea mays*) pollen from AZ AA:12:753 (ASM). (a) Single grain from Canal 3 (canal-flow sediment); (b) grain clump from Canal 3 (associated soil).

Materials and Methods

A total of 173 sediment samples was collected from eight canal features, exposed in 12 trenches, at AA:12:753. Approximately 30 g of sediments were obtained from rectangular excavations (1 cm high, 2 cm long, 2 cm deep) at microstratigraphic intervals of 2 cm to 10 cm, depending on strata thickness and availability. Samples were collected in plastic ziplock bags, which were labeled, dated, and sealed. Stratigraphic contexts were marked in feature profiles. From this set, 73 samples contained enough ostracodes for paleoecological analysis. Among these, samples were selected to reconstruct individual canal histories, to correlate equivalent strata among different trenches, and to define periodicity (seasonality) of canal operations.

Samples were prepared using a modified version of the protocol described by Forester (1991). Sediment residuals were analyzed under a low-power stereoscopic microscope. All 73 fossiliferous samples were examined to identify fossil contents and faunal assemblages. Total and relative abundances were recorded. Taphonomic features were used to determine origins of specimens (Delorme 1989; Forester 1988; Taylor 1992). Degrees of fragmentation and abrasion were used as indices of transport distances. Encrustation and coating were interpreted as indicators of authigenic mineralization or wave action, respectively. The redox index and color of each valve reflected burial conditions and calcification. The carapace/valve (C/V) and adult/juvenile (A/J) ratios were used as indicators of biocenosis, that is, local development of populations. The latter ratio is

commonly related to diagenetic effects. However, based on the relatively young stage of the canal sediments, the A/J ratios are considered good indicators of in situ or untransported local development of populations.

Additionally, comparisons with the granulometric (particle-size) analysis and lithostratigraphy of the canals were critical to determine ostracode origins and energy of transport. Coarse-grained sediments are commonly deprived of ostracodes, or support only adult forms, because these are more resistant to transport. In contrast, fine-grained sediments allow establishment of local populations where low-energy and nutrient-rich waters favor faunal settlement. Canal geomorphology and gradients (Chapter 7) were used to verify transport likelihood of ostracode valves.

The environmental characteristics where continental ostracodes grow are presented in Table 8.3, and the generalized conditions controlling the species present at AA:12:753 are summarized in Table 8.4. Based on species abundance, a paleosalinity index was used to establish the canal operation history (Palacios-Fest 1994). The paleosalinity index was derived from the equation:

SI = [4(% *Limnocythere n.* sp., cf. *L. paraornata*) + 3(% *C. vidua*) + 2(% *C. glaucus*) + (% *C. patzcuaro*)) - (% *H. brevicaudata*) + 2(% *P. unicaudata*) + 3(% *I. bradyi*) + 4(% *C. arcuata*)]

The index weights species with incrementally higher salinity tolerances positively and species with incrementally lower salinity tolerances negatively. *Limnocythere n.* sp., cf. *L. paraornata* is assumed to be a salinity-tolerant species, because it occurs in the standing-water phases in these canals (indicated by cienega-like sediments), not during water-input stages.

RESULTS

Stratigraphy and Sedimentology

Appendix G presents the sample identification number, lithology, and other characteristics of canal ostracode samples. Figure 8.6 illustrates canal stratigraphies in various trenches and correlates them across the site, from upstream (south-southwest) to downstream (north-northwest). The canal microstratigraphies show several strata of variable shape and thickness (see also Chapter 7). The grain-size frequency is shown in Figure 8.7, by canal, through time. Lithologically, the sediments are strongly dominated by silt and clay, except the Cañada del Oro flood deposit (Stratum 503), which consists of sand. Sediments range in texture from clay to sand and vary in color from dusky brown (5YR 2/2) to moderate yellowish-brown (10YR 5/4) (Appendix G).

Table 8.3. Environmental conditions in which continental ostracodes grow. (Some eurotopic species occur under a combination of conditions shown in this table. Stenotypic species are restricted to one or two water chemistry conditions. A combination of factors [e.g., temperature, salinity, water velocity, duration of water flow] also limits ostracode development.)

Habitat	Permanence	Temperature	Salinity	Chemistry
Stream	Permanent	Eurythermic	Euryhaline	Type I
Channeled flow	Perennial	Organisms adapted to a wide range of temperature	Organisms adapted to a wide range of salinity	Ca^{2+}. Mg^{2+}, HCO_3^--dominated (freshwater)
Standing	Ephemeral	Stenothermic	Stenohaline	Type II
Low or no flow	Periodical dry-out	Organisms constrained to a narrow temperature range	Organisms constrained to a narrow salinity range	Ca^{2+}-rich/HCO_3^--depleted, Na^+, Mg^{2+}, SO_4^{2-}
		Thermobiont 20-25°C		or Na^+, Mg^{2+}, Cl^--dominated (hardwater)
		Thermophillic ~20°C		Type III: Ca^{2+}-depleted/HCO_3^--rich, Na^+, Mg^{2+}, SO_4^{2-}
		Cryophillic 10-15°C		or Na^+, Mg^{2+}, Cl^--dominated
		Cryobiont <10°C		

Table 8.4. Generalized environmental conditions controlling assemblages of continental ostracodes in the canals at AZ AA:12:753 (ASM).

Species	Habitat	Permanence	Temperature[a]	Salinity[a]	Chemistry[a]
Limnocythere n. sp. cf. *L. paraornata*	Lake, pond, or stream	Ephemeral or permanent	Eurythermic	500-75,000 mg L^{-1}	Types I and II
Cypridopsis vidua	Lake, spring, or pond	Ephemeral or permanent	Eurythermic	100-4,000 mg L^{-1}	Types I and II
Cyprinotus glaucus	Lake, pond, or stream	Ephemeral or permanent	Eurythermic	10-10,000 mg L^{-1}	Types I and II
Candona patzcuaro	Lake or pond	Ephemeral or permanent	Eurythermic	200-5,000 mg L^{-1}	Type II (eventually Type III)
Herpetocypris brevicaudata	Stream, lake, or spring	Permanent	Eurythermic	200-3,000 mg L^{-1}	Type II
Potamocypris unicaudata	Pond, stream, and lake	Ephemeral or permanent	Eurythermic	100-3,000 mg L^{-1}	Types I and II
Ilyocypris bradyi	Stream, lake, or spring	Permanent	Eurythermic	100-4,000 mg L^{-1}	Types I and II
Chlamydotheca arcuata	Spring, stream, cienega, or pond	Permanent	Thermobiont	100-4,000 mg L^{-1}	Types I and II

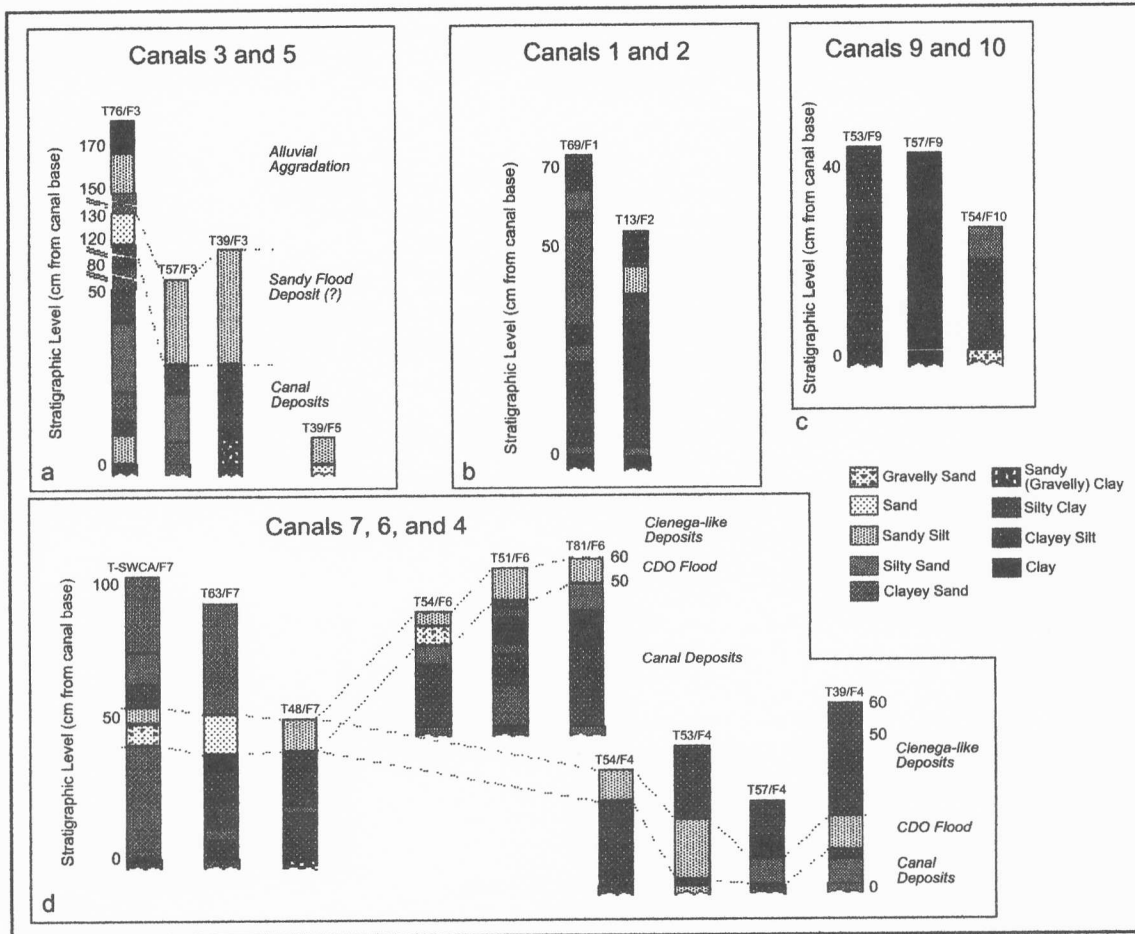[a]From Delorme (1989), Forester (1991), and Palacios-Fest (1994).

Figure 8.6. Lithostratigraphy of canals by trench, arranged from upstream to downstream (south-southwest to north-northeast), including main sedimentological events: (a) Canals 3 and 5; (b) Canals 1 and 2; (c) Canals 9 and 10; and (d) Canals 7, 6, and 4.

Ostracode Record

Table 8.5 presents the number of organisms recovered from each sample, including major groups —mollusks, gyrogonites (calcareous algae reproductive structures), vertebrate bone fragments, plant debris, and ostracode species. Nine species were identified. *Ilyocypris bradyi* was the most common and abundant throughout the set of samples. *Cypridopsis vidua* was second. *Limnocythere n.* sp., cf. *L. paraornata* occurred in several canals and intervals. Other species (*Cyprinotus glaucus, Herpetocypris brevicaudata, Candona patzcuaro, Chlamydotheca arcuata, Potamocypris unicaudata,* and *Cypridopsis* sp.) occurred occasionally. Some specimens were listed as unidentified and occurred sporadically in the canals. Based on the occurrences and relative abundances of these species, the assemblage was dominated by *I. bradyi,* a streamflow indicator. The faunal association is consistent with the water pathway

Types I (dilute) and II (Ca-enriched waters dominated additionally by Na^+, Mg^{2+}, and SO_4^{2-}) of Eugster and Hardie (1978).

Surface water and groundwater analyses of the modern Rillito Creek (sampled from August 1987 to August 1993) showed near-equivalent proportions of bicarbonate and Ca, with the latter slightly dominant (Tadayon 1995; Tadayon and Smith 1994). Therefore, the ostracode paleoecologic inference of the area's water chemistry is consistent with modern analyses. Main canal waters evolved from Type I to Type II as they reached the distal ends of minor canals and were subject to evaporation. This trend is shown by the increasing diversity and occurrence of *Limnocythere n.* sp., cf. *L. paraornata*, which indicates relatively warm, saline conditions.

Ostracode absolute and relative abundances, taphonomic features, and paleosalinity index values were computed for each sample. For each canal, the sequence of species distribution and inferred
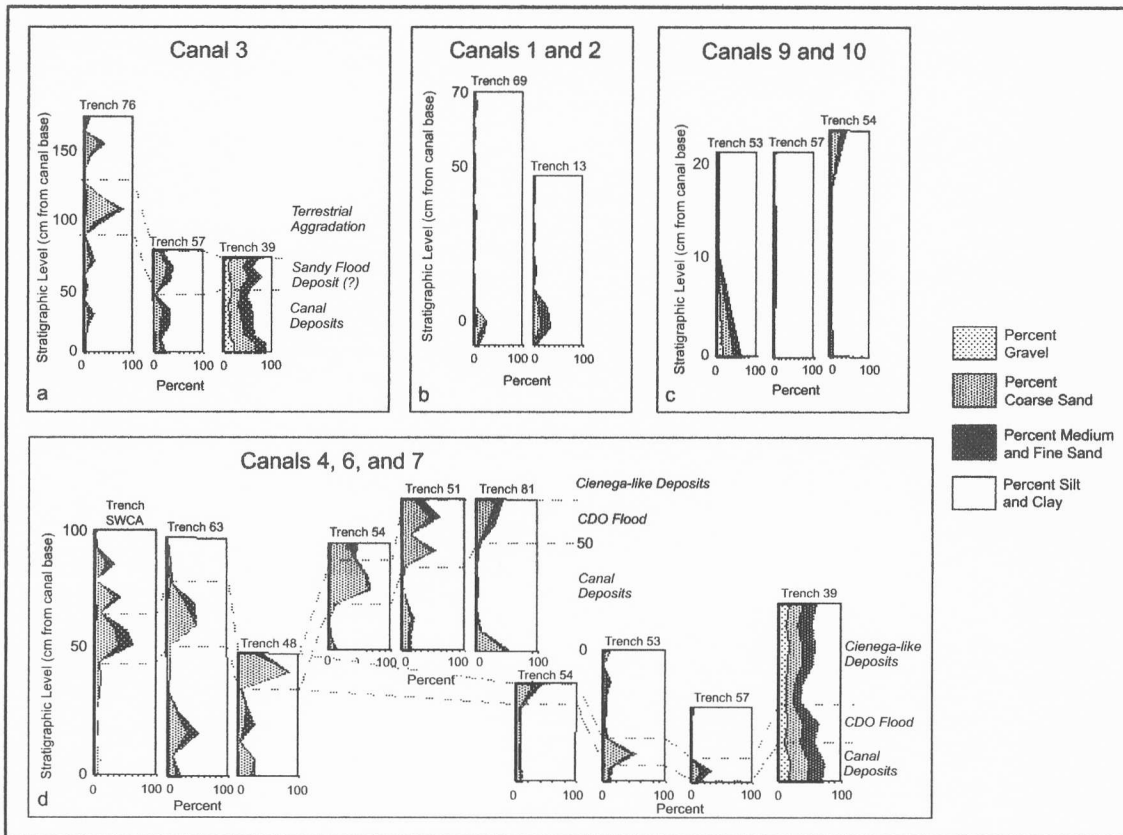
Figure 8.7. Granulometric (particle-size) percentages of sediments by canal and trench, arranged from upstream to downstream (south-southwest to north-northeast), including main sedimentological events: (a) Canal 3; (b) Canals 1 and 2; (c) Canals 9 and 10; and (d) Canals 4, 6, and 7.

paleoecology is used to interpret environmental transitions through time in the canals. The paleosalinity index developed for each canal is documented and correlated between upstream and downstream trenches in Figure 8.8. All fossil samples were characterized by a small population (1-504 individuals per sample) and low diversity (one to nine species). Taylor (1992) and Palacios-Fest (1997) demonstrated that small sample size is related to the degree of energy and water permanence, although ostracode occurrence may be attributed to transport or local growth. Based on Delorme (1969, 1989) and Forester (1988), taphonomic characteristics (listed above) were used to distinguish allochthonous (transported) from autochthonous (local) populations.

For each canal, the sequence of species distribution and inferred paleoecology was used to interpret environmental transitions through time in the canals. The paleosalinity index developed for each canal is documented in Figure 8.8, to correlate canals among trenches.

Early San Pedro Phase Canals

Two canals (3 and 5) represent the oldest record of irrigation agriculture at AA:12:753, during the early San Pedro phase; their ages are bracketed between roughly 1250 B.C. and 950 B.C. (see Figure 8.1). Canal 5 (Trench 15), constructed near 1250 B.C., was an aborted canal that never conveyed water (see Chapter 7) and is, therefore, unfossiliferous; it is not discussed further here. In contrast, Canal 3 was sampled from three trenches (76, 57, and 39). The samples from Trench 57 were unfossiliferous. Four samples contained ostracodes at the base of this canal in Trenches 76 (upstream) and 39 (downstream). Based on granulometric (particle-size) analysis, Figure 8.7a shows the accumulation of fine sediments associated with *I. bradyi* and *C. vidua*, the only two species recorded in Canal 3. The former is the dominant species. Relatively high fragmentation, high abrasion, and slight oxidation were observed in these specimens. Encrustation, or light coating, was noticed in the samples from Trench 39, where the redox

Table 8.5. Fossiliferous samples containing ostracodes from AZ AA:12:753 (ASM). (Stratigraphic level indicates distance from base of canal.)

Canal	Sample ID #	Stratigraphic Level (cm)	Total Populations					Ostracode Species									
			Ostracodes	Molluscs	Gyrogonites	Vertebrate Bones	Plant Debris	Ilyocypris bradyi	Cypridopsis vidua	Cypridopsis sp.	Herpetocypris brevicaudata	Limnocythere n. sp. cf. L. paraornata	Cyprinotus glaucus	Potamocypris unicaudata	Candona patzcuaro	Chlamydotheca arcuata	Unidentified
3	76-3-1	1	3	11	–	–	13	3	–	–	–	–	–	–	–	–	–
	76-3-2	9	17	–	–	–	18	15	1	–	–	–	–	–	–	–	1
	39-3-1	1	2	1	–	–	–	2	5	–	–	–	–	–	–	–	–
	39-3-3	9	9	4	3	–	–	9	–	–	–	–	–	–	–	–	–
4	54-4-3	20	6	1	–	–	9	6	–	–	–	–	–	–	–	–	–
	54-4-4	29	3	5	–	–	16	3	–	–	–	–	–	–	–	–	–
	53-4-1	1	25	10	–	–	–	22	–	–	–	3	–	–	–	–	–
	53-4-3	11	81	11	–	–	21	78	–	–	–	3	–	–	–	–	–
	53-4-4	21	29	14	–	–	34	17	12	–	–	–	–	–	–	–	–
	53-4-5	35	17	4	–	–	13	14	2	–	–	–	1	–	–	–	–
	57-4-1	1	49	4	–	2	–	47	2	–	–	–	–	–	–	–	–
	57-4-3	9	27	13	–	–	–	26	1	–	–	–	–	–	–	–	–
	57-4-4	11	4	19	–	–	–	4	–	–	–	–	–	–	–	–	–
	57-4-5	17	23	28	–	–	–	21	2	–	–	–	–	–	–	–	–
	57-4-6	23	40	14	–	–	–	39	1	–	–	–	–	–	–	–	–
	57-4-7	27	8	2	–	–	–	5	2	–	–	–	–	–	–	–	1
	39-4-1	1	37	4	–	–	–	32	1	–	–	4	–	–	–	–	–
	39-4-2	10	2	–	–	1	–	2	–	–	–	–	–	–	–	–	–
	39-4-3	11	1	–	–	–	–	1	–	–	–	–	–	–	–	–	–
	39-4-4	18	6	–	–	–	–	6	–	–	–	–	–	–	–	–	–
	39-4-5	25	32	67	–	–	–	24	6	–	–	2	–	–	–	–	–
	39-4-6	34	118	7	3	1	–	94	24	–	–	–	–	–	–	–	–
	39-4-7	42	8	1	–	–	–	5	3	–	–	–	–	–	–	–	–
	39-4-8	48	1	2	–	–	–	1	–	–	–	–	–	–	–	–	–
	39-4-9	55	2	2	–	–	–	2	–	–	–	–	–	–	–	–	–
6	54-6-1	1	371	20	–	–	34	361	6	–	–	4	–	–	–	–	–
	54-6-2	11	38	11	–	–	29	34	2	–	–	2	–	–	–	–	–
	54-6-3	20	10	19	–	–	21	10	–	–	–	–	–	–	–	–	–
	51-6-3	17	71	39	–	–	35	70	–	–	–	–	–	–	–	–	1
	51-6-4	26	12	2	–	–	19	12	–	–	–	–	–	–	–	–	–
	51-6-5	31	64	21	–	–	39	64	–	–	–	–	–	–	–	–	–
	81-6-1	1	53	12	–	–	26	51	–	–	–	1	–	–	–	–	1
	81-6-2	7	28	4	–	–	38	25	3	–	–	–	–	–	–	–	–
	81-6-3	17	79	21	–	–	46	76	–	–	–	3	–	–	–	–	–
	81-6-4	25	3	1	–	–	21	1	–	–	–	2	–	–	–	–	–
	81-6-5	35	81	9	–	–	65	76	1	–	–	2	–	–	–	–	2
	81-6-6	47	4	2	–	–	31	4	–	–	–	–	–	–	–	–	–
7	SWCA-7-16	-2	7	–	–	–	–	2	2	–	–	4	–	–	–	–	–
	SWCA-7-1	1	115	34	–	–	–	113	–	–	–	1	–	–	–	–	1

Table 8.5. Continued.

Canal	Sample ID #	Stratigraphic Level (cm)	Total Populations					Ostracode Species									
			Ostracodes	Molluscs	Gyrogonites	Vertebrate Bones	Plant Debris	Ilyocypris bradyi	Cypridopsis vidua	Cypridopsis sp.	Herpetocypris brevicaudata	Limnocythere n. sp. cf. L. paraornata	Cyprinotus glaucus	Potamocypris unicaudata	Candona patzcuaro	Chlamydotheca arcuata	Unidentified
7	SWCA-7-3	19	38	9	–	–	23	31	6	–	–	1	–	–	–	–	–
	SWCA-7-4	21	4	3	–	–	17	4	–	–	–	–	–	–	–	–	–
	SWCA-7-5	24	5	3	–	–	12	5	–	–	–	–	–	–	–	–	–
	SWCA-7-6	31	18	5	–	–	6	18	–	–	–	–	–	–	–	–	–
	SWCA-7-7	40	1	–	–	–	–	1	–	–	–	–	–	–	–	–	–
	SWCA-7-9	53	1	–	–	–	–	1	–	–	–	–	–	–	–	–	–
	SWCA-7-10	59	18	57	–	–	8	17	1	–	–	–	–	–	–	–	–
	SWCA-7-11	67	8	8	–	–	11	8	–	–	–	–	–	–	–	–	–
	SWCA-7-12	73	158	8	–	–	34	120	30	–	–	4	–	–	–	–	4
	SWCA-7-13	74	336	115	–	1	46	245	80	1	–	–	7	3	–	–	–
	SWCA-7-15	98	504	23	40	1	69	232	165	22	–	12	68	–	–	4	1
	63-7-2	8	4	3	–	–	13	4	–	–	–	–	–	–	–	–	–
	63-7-3	13	17	5	–	–	19	17	–	–	–	–	–	–	–	–	–
	63-7-4	20	17	9	–	–	28	16	–	–	–	1	–	–	–	–	–
	63-7-5	26	17	24	–	–	33	17	–	–	–	–	–	–	–	–	–
	63-7-9	64	151	1	–	–	39	140	9	–	–	2	–	–	–	–	–
	63-7-10	75	17	17	–	–	27	14	3	–	–	–	–	–	–	–	–
	63-7-11	93	3	1	–	–	18	–	3	–	–	–	–	–	–	–	–
	48-7-2	11	44	66	–	–	32	44	–	–	–	–	–	–	–	–	–
	48-7-3	16	35	3	–	–	21	35	–	–	–	–	–	–	–	–	–
	48-7-4	21	88	15	–	–	26	88	–	–	–	–	–	–	–	–	–
	48-7-5	35	4	6	–	–	14	4	–	–	–	–	–	–	–	–	–
1	69-1-20	-3	252	43	2	1	–	125	107	–	1	17	–	1	1	–	–
	69-1-1	1	37	74	2	–	–	34	1	–	2	–	–	–	–	–	–
	69-1-2	11	11	16	–	–	–	5	5	–	1	–	–	–	–	–	–
	69-1-3	16	11	9	–	–	–	3	6	–	1	1	–	–	–	–	–
	69-1-4	22	5	–	–	–	–	4	–	–	–	–	–	–	–	–	–
	69-1-5	27	28	2	–	–	–	13	2	–	–	9	–	3	–	–	1
	69-1-6	31	32	9	–	–	–	12	9	–	–	8	–	3	–	–	–
2	13-2-2	7	11	3	–	–	45	8	3	–	–	–	–	–	–	–	–
	13-2-3	14	100	10	–	–	52	80	16	–	–	–	–	–	–	–	4
	13-2-6	37	2	1	–	–	94	2	–	–	–	–	–	–	–	–	–
	13-2-7	41	1	1	–	1	16	1	–	–	–	–	–	–	–	–	–
	13-2-8	46	8	17	–	–	21	4	–	–	–	4	–	–	–	–	–

index changed from low oxidizing to reducing conditions.

Late San Pedro Phase Canals

Three canals (4, 6, and 7) represent the second generation of irrigation agriculture at the site, during the late San Pedro phase; their ages are bracketed between 950 B.C. and 800 B.C. (see Figure 8.1). Fine sediments were associated with fossiliferous samples (see Figure 8.7d). Canal 7 was sampled from three trenches (SWCA Trench, Trench 63, and Trench 48). The SWCA Trench, the furthest upstream, provided 13 fossiliferous samples. Samples SWCA-7-1 to
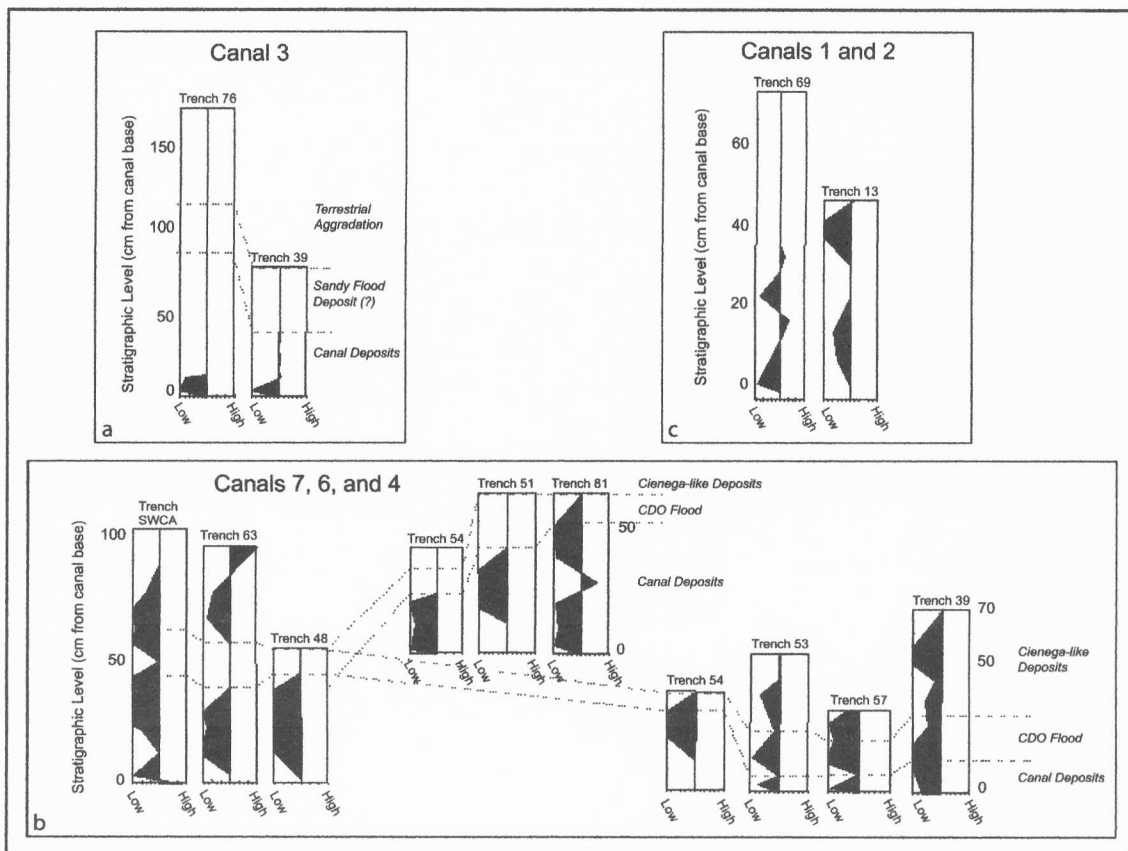
Figure 8.8. Paleosalinity index derived from ostracode relative abundance (see text for explanation), by canal and trench, including spatial correlation among trenches: (a) Canal 3; (b) Canals 7, 6, and 4; (c) Canals 1 and 2.

SWCA-7-9 represented canal use. The reference sample (SWCA-7-16) — collected 2 cm beneath the canal surface — contained a small assemblage of ostracodes consisting of *I. bradyi*, *C. vidua*, and *Limnocythere n.* sp., cf. *L. paraornata*, suggesting a cienega-like substrate. Samples SWCA-7-10 to SWCA-7-15 suggested post-use, cienega-like deposits (see Table 8.5). The SWCA Trench provided the richest and most diverse assemblage from Canal 7, including *I. bradyi*, *C. vidua*, *Cypridopsis* sp., *Limnocythere n.* sp., cf. *L. paraornata*, *C. glaucus*, *P. unicaudata*, and *C. arcuata* throughout the stratigraphic sequence. Degrees of fragmentation and abrasion were low. Encrustation and coating were absent in the lower portion, but increased toward the top of the section. In contrast, the redox index showed low oxidation throughout.

From Trench 63, Canal 7 provided seven fossiliferous samples where diversity declined substantially to three species: *I. bradyi*, *C. vidua*, and *Limnocythere n.* sp., cf. *L. paraornata*. Samples 63-7-2 to 63-7-5 represented canal operation; samples 63-7-9 to 63-7-11 represented sediments that accumulated ostracodes after the Cañada del Oro flood (Stratum 503) that

ended the use-life of the canal. The taphonomic characteristics included moderate fragmentation, abrasion, and encrustation, and low oxidation of valves. The downstream trench (48) where Canal 7 is exposed is monospecific, consisting of *I. bradyi* present in four samples. All four samples were collected from strata representing canal operation. Specimens were moderately fragmented; abrasion and encrustation were low. The redox index suggested low oxidation of valves.

Further downstream, Canal 7 branched into Canals 4 and 6. Canal 6, branching to the north, was exposed in Trenches 54, 51, and 81. In Trench 54, three samples from Canal 6 were fossiliferous, with *I. bradyi*, *C. vidua*, and *Limnocythere n.* sp., cf. *L. paraornata* represented. All three samples contained ostracodes indicating canal operation. Moderate-to-low fragmentation, abrasion, and encrustation characterized the assemblage. Low coating occurred only in the uppermost fossiliferous sample. The redox index suggested low oxidized valves.

To the east, Trench 51 provided three fossiliferous samples from Canal 6. All three samples represented canal operation. The assemblage was primarily

monospecific, consisting of *I. bradyi* (an unidentified species was collected at the base of the canal). Fragmentation was moderate, but abrasion was low. Encrustation and coating were also low, whereas the redox index increased from low-to-moderately oxidized valves.

The downstream Trench 81 provided six fossiliferous samples from Canal 6, hosting four species: *I. bradyi*, *C. vidua*, *Limnocythere n.* sp., cf. *L. paraornata*, and an unidentified species. *I. bradyi* was the dominant species; all others occurred sporadically throughout the sequence. All six samples were collected below the Stratum 503 flood deposit and represented canal operation. Fragmentation ranged from moderate to high, but abrasion was moderately low; encrustation was low. Coating was low except in a sample (81-6-2) approximately 7 cm from the base of the canal, where it was high (95 percent). The redox index showed low oxidation of valves.

Canal 4, the south fork of Canal 7, was exposed in four trenches. Upstream, Trench 54 provided two fossiliferous, but monospecific, samples; only *I. bradyi* was present. Both samples were obtained from strata below the Cañada del Oro flood deposit. Moderate-to-low fragmentation, low abrasion, and low encrustation characterized the assemblage. The redox index showed low oxidation of valves.

Downstream, Trench 53 provided four fossiliferous samples. Sample 53-4-1 was the only one collected from below the Cañada del Oro flood deposit (Stratum 503) and represented canal operation; all other sampled sediments represented post-use accumulation. Fragmentation was moderate, but abrasion and encrustation were low. The redox index showed low oxidation of valves.

Trench 57 provided six fossiliferous samples from further downstream in Canal 4. Sample 57-4-1 was also the only sample collected from beneath the Cañada del Oro flood deposit (Stratum 503) and represented canal operation; the remaining five samples were from sediments that accumulated after the flood. Three species were present: *I. bradyi*, *C. vidua*, and an unidentified species. Fragmentation and abrasion ranged from moderate to low. Encrustation was low, and the redox index showed fluctuating oxidizing conditions.

Finally, the furthest downstream trench (Trench 39) provided nine fossiliferous samples. Samples 39-4-1 to 39-4-4 were collected from below the Cañada del Oro flood deposit (Stratum 503) (Sample 39-4-5), while the rest (39-4-6 to 39-4-9) were collected from sediments that accumulated after the Cañada del Oro flood. Fragmentation fluctuated from low to high; abrasion ranged from moderate to low. Encrustation, coating, and the redox index were high in the lower portion of the record only.

Cienega Phase Canals

Two canals (1 and 2) represent the last interval of irrigation agriculture—during the Early Cienega phase (circa 800 B.C.-500 B.C.) at AA:12:753 (see Figure 8.1). Fine sediments accumulated throughout most of the stratigraphic sequences in both canals (see Figure 8.7b). Canals 1 and 2 are not directly connected, but they correlate in time; therefore, they are discussed together. Canal 1 (Trench 69) provided six fossiliferous samples containing *I. bradyi*, *C. vidua*, *H. brevicaudata*, *Limnocythere n.* sp., cf. *L. paraornata*, *P. unicaudata*, *C. patzcuaro*, and an unidentified species. Fragmentation was moderate, but abrasion was low. Encrustation was not significant except in one sample (69-1-3). The redox index showed low-to-moderate oxidation of valves. Canal 2 (Trench 13) provided four fossiliferous samples, including *I. bradyi*, *C. vidua*, *Limnocythere n.* sp., cf. *L. paraornata*, and an unidentified species. Fragmentation was moderate to high, abrasion was low, and the redox index showed low oxidizing conditions.

Modern Canals

Samples from the modern canals (9 and 10) exposed in Trenches 53, 54, and 57 were unfossiliferous. Homogeneous sedimentation rates are inferred from Figure 8.6c. These canals were apparently fed by wells for short periods of time, preventing them from hosting ostracodes. No further discussion is possible regarding them.

Interpretations

Based on the combined faunal and sedimentological compositions of the canal sediments, some preliminary interpretations are possible. Pulses of water input from the Santa Cruz River are indicated by the ostracode fauna. The 35 intervals sampled in Canal 3 from Trenches 76, 57, and 39 show fast streamflow conditions at the base that introduced *I. bradyi* and *C. vidua*. The occurrence of a primarily adult population of these two species, indicative of streamflow, suggests reworking of valves from the Santa Cruz River, as also suggested by fragmentation, abrasion, and the C/V and A/J ratios. However, juveniles may not have been preserved in the deposit. After these initial pulses, the flow stopped abruptly and fine sediments accumulated but did not support ostracodes. This implies floodplain aggradation with eventual transport of channelized sands (e.g., 105-125 cm) in some areas (Trench 76).

The record of the early San Pedro phase Canal 3 suggests it was used opportunistically to divert

ephemeral flows following storms. This interpretation is supported by the adult-dominated, almost monospecific, assemblage of *I. bradyi* and *C. vidua* (rare), as well as the high levels of fragmentation and abrasion. The paleosalinity index shows dilute water input into the canals during operation. In Trench 39, (downstream end of canal; 280 m from Trench 76) slow-moving to standing water allowed the occurrence of aquatic gastropods (e.g., *Physa virgata*) and calcareous algae (oogonia of *Chara*), as well as higher salinity from evaporation (see Figure 8.8a).

A different mode of canal operation is indicated during the late San Pedro phase. The 87 intervals sampled from three interconnected canal Features (7, 6, and 4) show a consistent pattern of water pulses before the Cañada del Oro flood (Stratum 503). Systematic management of water inputs in canals is indicated for the first time by the ostracode record. The upstream end of Canal 7 (at the SWCA trench) supported *Limnocythere n.* sp., cf. *L. paraornata* and *C. vidua* at the base of the canal, probably because the canal was dug into a cienega-like deposit. Fragmentation and abrasion are low in this location, suggesting an in situ population.

During canal operation, two cycles of water input, separated by a period of evaporation, are evident. The same pattern, although not as marked as before, is observed in Trench 63 approximately 70 m downstream. One explanation for this apparently short evaporative event is that the freshwater input actually represents the upper event of two pulses recorded in the SWCA Trench. Then, at Trench 48 — located about 120 m downstream from SWCA Trench — only one cycle of water input is recorded. This correlates well with the upper event observed in the SWCA Trench and Trench 63. If water flow was sustained for several days or weeks, freshwater would have reached the downstream parts of the canals and supported ostracode populations (see Figure 8.8b).

Where Canal 7 forks into Canals 6 and 4, one or two freshwater pulses into the canals can be recognized. Low-to-moderate fragmentation and abrasion and low A/J ratios suggest in situ ostracode populations. For example, in Trench 54, Canal 6 (160 m downstream from SWCA Trench), shows two cycles of water input, with a minor cycle of evaporation in between. At Trench 51 (200 m downstream from the SWCA Trench), only one cycle of freshwater input is detected; however, in Trench 81 (240 m downstream from the SWCA Trench), two cycles are well defined. A sharp episode of salinization is marked between the two freshwater pulses at this location. There are two possible explanations: (1) an interruption of water flow associated with headgate closing,

causing evaporation; or (2) backflow from the agricultural fields. Either of these alternatives would have increased the amount of salts in solute composition. However, a prolonged exposure to high salinity would be necessary for ostracodes to record this change, and backflow would have increased salinity only temporarily before renewed forward flow of fresh water would have diluted the salts (see Figure 8.8b).

Canal 4, the south fork of Canal 7, also shows evidence of canal water management. In Trench 54 (160 m downstream from the SWCA Trench), only one episode of freshwater input is clear. Moderate fragmentation and abrasion of *I. bradyi* indicate the species was introduced with the flow. The same pattern is obvious 10 m downstream in Trench 53. In Trench 57 (185 m downstream from SWCA Trench), the canal shows two or three freshwater pulses. The first pulse was followed by a severe evaporation event suggesting water input was brief, thereby preventing ostracodes from settling and growing. *I. bradyi* and *C.vidua* were introduced by water flow. The second pulse includes a minor evaporation episode, or slower flow, which allowed *C. vidua* to increase in population. Trench 39 (230 m downstream from SWCA Trench) shows one flooding episode. The occurrence of *Limnocythere n.* sp., cf. *L. paraornata* — a species characteristic of higher temperatures and salinities — at the base of Canal 4 suggests canal operation was conducted during the late spring-early summer, the hot and dry period before the monsoon season. Subsequent freshwater input decreased the salinity to below the tolerance of *Limnocythere n.* sp., cf. *L. paraornata L. bradburyi*'s (1,000 ppm; Forester 1987), thereby preventing it from growing in this canal (see Figure 8.8b).

There are two possible explanations for the alternate occurrence of water pulses along the canals. First, canal sediments may have been occasionally cleaned out in some sections, destroying evidence of earlier flows. Therefore, only one cycle of water input would be recorded (e.g., Trenches 48, 51, and 54). The other possibility is that these pulses reflect the extensions of canal lengths as the irrigators increased in population and their subsistence needs increased. The former explanation is probably the most likely, because it would explain why some distal intervals record two cycles of water pulses. Additionally, assuming these sediments represent the last canal operation, it is reasonable to think that not all segments of the canals were cleaned. Only the areas where silt accumulation constricted the flow would have to be dredged. The second explanation, although intriguing, does not seem to explain why distal trenches show two cycles, while intermediate ones do not.

Across the area covered by this study, the Cañada del Oro flood deposit (Stratum 503) caps canal-flow deposits in Canals 4, 6, and 7. In most areas, the flood sands are deprived of ostracodes, except in the SWCA Trench and Trench 39, where ostracode populations were low and consisted of a maximum of two species (*l. bradyi* and *C. vidua*). Following this flood, and possibly as a result of it, a marshy cienega formed. The cienega soil is visible in several trenches (SWCA Trench, Trenches 63, 53, and 39). Based on the ecology of the ostracode species (cf. Palacios-Fest 1994, 1997) recovered from this cienega deposit, marshy conditions are inferred to have lasted for at least several weeks to allow *C. arcuata* and *C. glaucus* to become established. The genus *Limnocythere* is able to develop in a short period of time (about a month) in still, saline waters. However, the absence of *Limnocythere n.* sp., cf. *L. paraornata* offers no explanation. It would be expected to find this species as salinity increases with evaporation. Salinity certainly increased, as shown in Trench 63, where *C. vidua* flourished and replaced *l. bradyi*.

Two Cienega phase canals (Canals 1 and 2 in Trenches 69 and 13, respectively) show similar trends (see Figure 8.7b), raising the possibility that they were operated contemporaneously with the formation of the cienega deposit. The 26 intervals sampled within canal deposits showed that, as in Canals 7, 6, and 4 during the late San Pedro phase, systematic water management was conducted. Canal 1 accumulated a more diverse assemblage than Canal 2, which included *C. patzcuaro*, a species requiring over three months to reach maturity (Forester 1987; Palacios-Fest 1994, 1997). The occurrence of *Limnocythere n.* sp., cf. *L. paraornata* and *P. unicaudata* at the tops of the sequences suggests standing water and increasing evaporation due to cessation of canal operation. However, the freshwater pulses and evaporitic cycles are consistent between the two canals. The moderate fragmentation of *I. bradyi* and the low fragmentation, abrasion, and low A/J ratio of most other species suggest the specimens preserved in these canals grew in situ following episodes of freshwater input.

The modern (post-World War II) Canals 9 (Trenches 53 and 57) and 10 (Trench 54) had no ostracodes. The water sources for these modern canals were pump wells that operated episodically for only short periods of time, thereby preventing ostracodes from developing in these canals.

CONCLUSIONS

Climate

Temperature, precipitation, and seasonality during the timespans of canal use were not significantly

different from today — based on the similarity of the fossil pollen percentages with modern percentages. However, the ostracode assemblages are richer and more diverse in the late San Pedro phase canals (7, 6, and 4) than in the early San Pedro phase canal (3), suggesting two situations. During the late San Pedro phase, climate was probably somewhat warmer and drier than during the early San Pedro phase, 200-300 years earlier, allowing the occurrence of more salinity-tolerant species. This interpretation is reasonable, because in some trenches, *Limnocythere n.* sp., cf. *L. paraornata* occurs in Canal 4 at stages that indicate slow flow-to-standing water conditions, more susceptible to the effects of temperature.

Floodplain Environment

The pollen spectra indicate that, during the use-lives of the early and late San Pedro phase canals (Canals 3 and 4, respectively), the local vegetation was similar to that of the area today. The streamside vegetation of the Santa Cruz River probably included trees such as cottonwood (*Populus*), ash (*Fraxinus*), willow (*Salix*), sycamore (*Platinus*), and walnut (*Juglans*). Away from the channel margins, the floodplain was covered by a shrub steppe, dominated by salt sage (*Atriplex canescens, A. polycarpa*), pigweed (*Chenopodium album*) and other members of the Chenopodiacea, and carelessweed (*Amaranthus palmeri*). Riparian vegetation was nearby, and water frequently filled the channels of the Santa Cruz, Rillito, and Cañada del Oro. However, low percentages of pollen show that no wet-ground vegetation grew on the site itself. This indicates the canals did not contain water for long enough throughout the year to support wet-ground vegetation.

The ostracode fauna suggests that, throughout the canal sequence, irrigation was conducted in an active floodplain with a high water table. After the Stratum 503 flood ended the use-lives of the late San Pedro phase canals, a cienega deposit formed. Initially, this marshy soil was slightly saline due to evaporation when the water table was low. It then experienced a drastic dilution effect, probably due to a rise in the water table. The disappearance of ostracodes at the top of the cienega deposit implies a subsequent drop in the water table.

Evidence for Cultivation

The presence of maize (*Zea mays*) pollen in five of the 16 samples confirms local cultivation. It is present in both the soil (local pollen assemblage) and canal fill (extralocal assemblage) pollen samples. However, the extent of cultivation during use of the

early San Pedro phase canal was not great—based on the relatively low pollen percentages of weeds characteristic of the disturbed soils of agricultural fields.

Changes in Canal Operation

Based on the small sizes and flow directions of previously identified prehistoric canals in the Tucson Basin, it was suggested that Hohokam farmers of later prehistory in this region were only able to divert ephemeral drainages after storms (Fish et al. 1992). Contradicting this model, dominance of *I. bradyi* throughout the canal ostracode record at Las Capas indicates input from the Santa Cruz River. However, ostracode paleoecology showed the transition from opportunistic to systematic canal operation between the early and late San Pedro phase.

As defined here, opportunistic canal operation consists of opening the canal headgate when ephemeral drainages flow during storms. Systematic canal operation implies human control of water flows into the canal, and for longer durations (but not necessarily continuously throughout the year). For example, Palacios-Fest (1997) demonstrated that, in the Phoenix Basin during the Classic period, systematic canal operation was mastered by the Hohokam living at Pueblo Blanco (AZ U:9:92, 95, 97, 128 [ASM]).

The earlier Canal 3 represents an opportunistic mode of canal operation that allowed the growth of only *I. bradyi* in a downstream trench (39), with increasing evaporation. The thin accumulation of canal-flow sediments and the poor, almost adult, faunal composition advocates for one episode of water input. The canal fill of this canal has higher percentages of Chenopodiaceae/*Amaranthus* pollen and lower percentages of charcoal than does the main late San Pedro phase canal (4). This suggests a lesser contribution of water-transported pollen, and therefore,

shorter or less intense utilization than during Canal 4 use.

The late San Pedro phase farmers managed to better control water input into canals. These younger canals were used for a prolonged period of time, accumulating thick layers of water-lain sediments. Although still dominated by *I. bradyi*, the late San Pedro phase ostracode assemblages have higher diversities, indicating episodes of water input alternated with intervals of evaporation. Some of these cycles included canal desiccation, while others were characterized by an increase in salinity and a subsequent return to dilute water conditions. These pulses of water input appear to have a human origin rather than a climatic origin, and are consistent with repeated opening and closing of canal headgates. (The fact that Canals 1 and 2 show a similar pattern suggest an interpretation of systematic canal management during the Cienega phase.)

It is also significant that the late San Pedro phase farmers were able to tap the perennial, groundwater-fed flow of the river to irrigate their fields in the dry "foresummer" of May-June, as indicated by the presence of *Limnocythere n.* sp., cf. *L. paraornata*—a species characteristic of higher temperatures and salinities—at the base of Canal 4. Irrigation during this period ensured early germination of maize seeds, such that the plants reached the proper stage of growth to achieve maximum benefits from the rains of the "monsoon summer" from July to mid-September.

Based on the paleoecological signal left by ostracodes, it is also evident that the canals were periodically cleaned to remove salts, debris, and sediments. The ostracode paleoecology suggests cleaning was probably less frequent during the early San Pedro phase, and probably did not include all the entire distance of the canal. This supports geomorphological evidence of only localized clean-outs of Canal 3 (see Chapter 7).

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