BOTANICAL SIGNATURES OF WATER STORAGE DURATION IN A HOHOKAM RESERVOIR

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Although large-scale canal irrigation technology is commonly associated with the prehistoric Hohokam (A.D. 200–1450) of south-central Arizona, earthen reservoirs were essential for domestic water storage in areas of the Sonoran Desert away from perennial streams. Interpretations of seasonal water storage in prehistoric Hohokam reservoirs are often based on direct analogy with the historic Tohono O'odham (formerly called the Papago). This assumption of seasonal water storage is a hypothesis that should be tested rather than uncritically accepted by archaeologists. Sediments recovered with a hand-driven bucket auger from an earthen reservoir at a large Classic-period (ca. A.D. 1200–1450) Hohokam site (AZ AA:3:32 [ASM]) yielded uncarbonized seeds of an aquatic plant belonging to the genus Lemna (duckweed). The high number of Lemna seeds indicates that water may have been stored on a long-term, perhaps perennial, basis. Analyses of sediments from other reservoirs should generate further discoveries of uncarbonized seeds or other biological remains (e.g., pollen, phytoliths, diatoms, snails) and refine our understanding of prehistoric water storage facilities throughout the world.

A pesar de que los sistemas de canales de irrigación a gran escala han sido asociados con la cultura prehistórica Hohokam (200–1450 d.C.) del centro-sur de Arizona, los estanques constituyeron una fuente esencial de almacenamiento de agua para uso doméstico en aquellas zonas del Desierto de Sonora alejadas de arroyos o corrientes perennes. Frecuentemente, las interpretaciones sobre el almacenamiento de agua estacional de los Hohokam están basados en analogías con los indígenas Tohono O'odham (antes llamados Papagos). Esta suposición es aún una hipótesis que debe ser verificada y no simplemente aceptada sin el apropiado análisis crítico. Recientemente, mediante el uso de un perforador manual tipo "auger," recuperamos sedimentos de uno de estos estanques que data del período Clásico (ca. 1200–1450 d.C.). El sitio Hohokam (AZ AA:3:32 [ASM]) contuvo semillas en buen estado (no carbonizadas) de una planta acuática del género Lemna. La abundancia de las semillas de Lemna indican que el agua debió haber sido almacenada por un largo período, posiblemente perenne. Es de esperar que los análisis de los sedimentos de otros estanques generen nuevos descubrimientos de semillas u otros restos orgánicos (e.g., polen, fitolitos, diatomeas, gasterópodos) en buen estado y nos permitan refinar nuestro conocimiento sobre el almacenamientos prehistórico de agua alrededor del mundo.

The prehistoric Hohokam (ca. A.D. 200–1450) of the Sonoran Desert in south-central Arizona provide an important archaeological example of the relationship between water management technology and settlement patterns. A widespread emphasis on agriculture, ceramic manufacture, and the habitation of pithouses, or surface pueblos enclosed by adobe compounds, characterized most Hohokam populations. Throughout the Hohokam sequence, communities of related settlements typically surrounded public monuments such as ball courts (Preclassic period) and platform mounds (Classic period) (e.g., Doyel 1979; Fish and Fish 1991).

The Hohokam are most noted for a large-scale canal irrigation network that exceeded a linear distance of 500 km (Masse 1991) and rivaled the scale of irrigation works found in much of ancient Mexico (Doolittle 1990). In the Classic period (ca. A.D. 1200–1450), settlements with platform mounds presumably functioned as administrative centers, where community leaders regulated the timing and allocation of water resources (Howard 1987:212, 1993; Neitzel 1987, 1991; Nicholas

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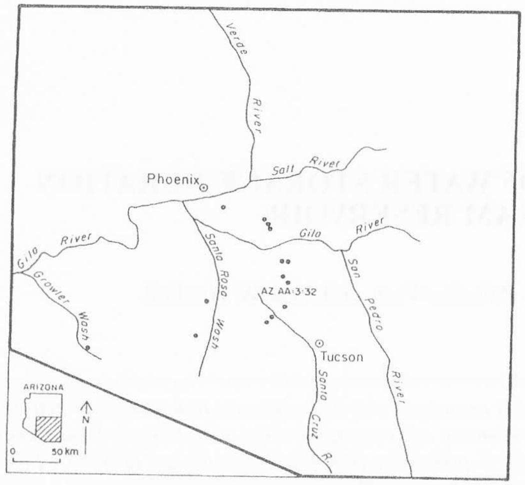

Figure 1. Classic Hohokam sites with reservoirs in southern Arizona (Bayman 1993; Bayman and Fish 1992). Drafted by Ronald Beckwith.

and Feinman 1989; Nicholas and Neitzel 1984).

A concentration of large canal systems and associated sites in the Salt and Gila river valleys of the Phoenix Basin has long been viewed as the Hohokam core or Riverine Hohokam (e.g., Gladwin 1928; Haury 1976; Schroeder 1940). Areas to the south and west of Phoenix and Tucson where large-scale canals are absent made up one portion of the Hohokam periphery, or Desert Hohokam (Haury 1976; see McGuire 1991 for extended discussion). Haury's (1976) belief that the Hohokam were tethered to riverine irrigation systems was based on early archaeological research, which, with few exceptions, was quite limited in the periphery (i.e., Haury 1950; Scantling 1940; Withers 1973).

Recently acquired survey data suggest that this core-periphery perspective warrants considerable revision. In several locales of the Hohokam "periphery," field research during the past 15 years has identified a widespread system of agricultural production that is located away from the major streams and rivers (e.g., Fish et al. 1992). A growing number of reservoirs also has been documented throughout the Sonoran Desert (e.g., Antieau 1981; Bayman 1993; Crown 1987; Hayden 1931; Wilcox and Sternberg 1983), and a few have been excavated (e.g., Ciolek-Torrello and Nials 1987; Dart 1983; Raab 1975).

Although reservoirs were constructed and used throughout the Hohokam sequence, this study focuses on the Classic period (A.D. 1200–1450) for which widespread dry-farming and reservoir construction have been documented in the nonriverine deserts (Bayman and Fish 1992). Interpretations of Hohokam subsistence and settlement in the periphery are often based on an implicit assumption that reservoirs were nonperennial sources of domestic water, an inference derived by direct analogy with the dual settlement system of the historic Tohono O'odham, formerly called the Papago (Gasser 1979). Some ethnographic records (e.g., Castetter and Bell 1942:42–43; Underhill 1939) describe lowland summer villages that relied on earthen reservoirs for storing domestic water. After the summer rains, reservoirs dried, and villages were established in the uplands, where water was retrieved from wells and springs.

A critical reevaluation of these ethnographic accounts, new archaeological data, and analyses of modern stock pond records led one of us to propose that prehistoric Hohokam reservoirs were effective devices for long-term, perhaps perennial, water storage (Bayman 1993; Bayman and Fish 1992). The following discussion presents an empirical test of this hypothesis by augering for botanical remains from archaeological deposits in an earthen reservoir at a Late Classic (A.D. 1250–1350) Hohokam village (AZ AA:3:32) (ASM) in southern Arizona (Figure 1).[1]

Although further research is clearly warranted, the discovery of uncarbonized *Lemna* seeds in reservoir sediments provides archaeological evidence of long-term water storage that is not implied by ethnographic accounts (e.g., Castetter and Bell 1942; Underhill 1939). This long-term storage of water in Hohokam reservoirs has important implications for water management and regional economy in preindustrial irrigation societies elsewhere in the world (e.g., Kennedy 1995; Scarborough 1988, 1991, 1993; Scarborough and Gallopin 1991). Before discussing the implications of this study, we first summarize the substantive findings of our reservoir augering program.

Description of Reservoir

The reservoir at site AZ AA:3:32 (ASM) consists of a bowl-shaped pit that is bordered by earthen

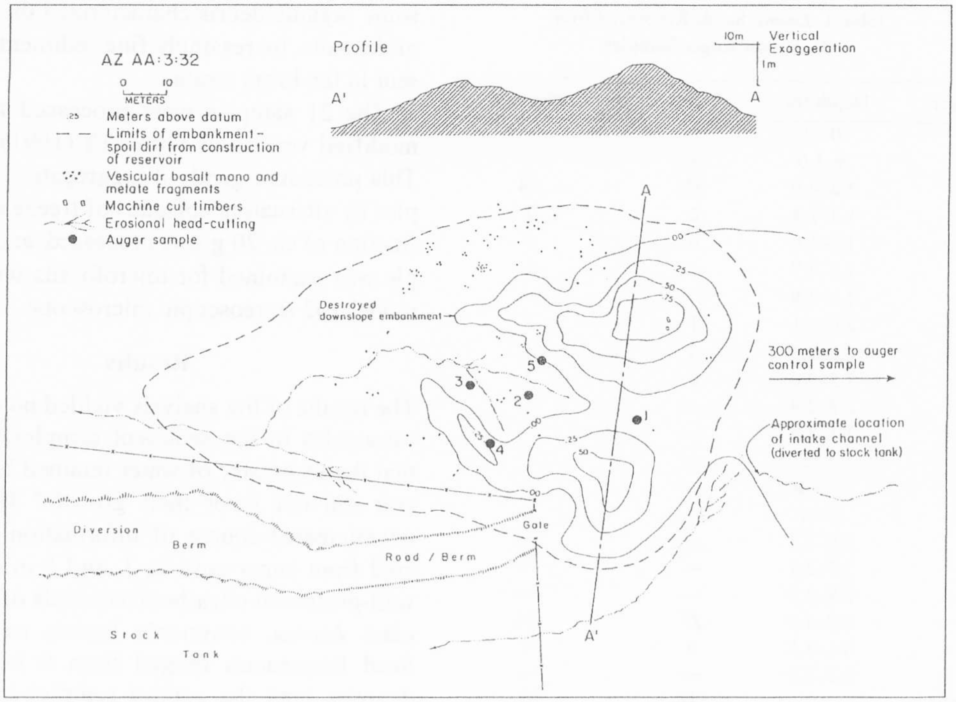

Figure 2. Location of auger units in reservoir at site AZ AA:3:32 (ASM). Drafted by Ronald Beckwith.

embankments (Figure 2). Dimensions of the reservoir are ca. 70 x 40 m; augering indicates that it is no less than 3.5 m to the base of the reservoir. When the estimated height of the original embankments (2 m) is included, it is clear the reservoir was over 4 m deep and could have held a substantial amount of water.[2] With one exception (Dart 1983), this is the largest Hohokam reservoir thus far investigated.

Rationale for Augering

This particular reservoir was selected for study for a number of reasons. First, it is located in a nonriverine setting between the Gila and Santa Cruz rivers. Second, the reservoir is associated with a large Classic-period site (exceeds 2 km^2 in area) that contains numerous adobe rooms, walled compounds, and refuse middens. Water requirements would have been quite substantial for activities such as adobe manufacture, food preparation, and domestic consumption. Third, Arizona Department of Hydrology records on a modern stock pond at the site indicate that it holds water for 12 months of the year (Bayman 1993; Bayman and Fish 1992). The presence of this stock pond adjacent to the reservoir suggests that the prehistoric site may have been selected for its topographic location, which was suitable for year-round water storage in reservoirs.[3]

Although these multiple lines of evidence suggest that water could have been stored on a long-term, even perennial, basis in the reservoir, this hypothesis has not yet been tested with archaeological data. Augering for biological remains is an appropriate method for testing this hypothesis (Stein 1986), because certain floral and faunal species cannot be sustained without perennial water.

Methods

Augering is often used by earth scientists to recover samples of subsurface deposits, and this method was highly appropriate for our study. An auger is a device that cuts subsurface deposits in a helical motion and retains a cutting (or sample) from the bottom of the bore hole (Stein 1986:505).

Augering Program

The original goal of the augering program was to assess the permanence of water in prehistoric

Table 1. *Lemna* Seeds Recovered from Reservoir Auger Samples

Auger	Depth (m)	Count	Percentage
1	.0–.2	—	—
	.9–1.0	—	—
2	3.8–4.0	62	54
3	1.3–1.4	2	2
	1.5–1.6	6	5
	1.6–1.7	—	—
	1.7–1.8	—	—
	2.0–2.1	1	1
	2.2–2.3	5	4
	2.5–2.6	6	5
	2.8–2.9	—	—
	3.1–3.2	—	—
4	.0–.2	—	—
	.9–1.0	—	—
5	.5–.6	—	—
	2.6–2.7	—	—
	2.7–2.8	—	—
	2.8–2.9	—	—
	2.9–3.0	27	24
	3.1–3.2	5	4
	3.2–3.3	—	—
Total		114	99

reservoirs through the recovery of ostracodes from sediments within these features, because these microscopic crustaceans have been found in areas with histories of perennial water such as irrigation canals (e.g., Palacios-Fest 1989, 1994). Systematic samples from deposits in the reservoir at site AZ AA:3:32 (ASM) were recovered with a hand-driven, 3-inch-wide (7.62 cm) bucket auger. A total of 88 sediment samples were obtained from five auger units (Figure 2). In each case, samples were collected at 20- to 25-cm intervals until the auger reached a hard, impermeable caliche (calcium carbonate) substratum at the base of the feature.

Sample Processing

Twenty-one sediment samples were selected for micropaleontological analysis from the auger units (Table 1). The samples were intentionally chosen to include sediments from a range of depositional and vertical proveniences within the reservoir. Sediment grain size among the samples ranged from coarse gravel in the feature's upper deposits to fine alluvium in the feature's lowest deposits. Based on the Munsell color system, sediment color varied from reddish (5R4/6) to reddish brown (10R4/6). Massive stratification and some organic debris characterized the upper 1 m of deposits. Increasingly fine sediments were present in the lower strata.

The 21 samples were processed following a modified version of Forester's (1991) technique. This procedure gently disaggregates friable samples by alternating episodes of freeze and thaw. A fraction of ca. 20 g was processed, and each sample was examined for microfossils with a Nikon model 102 stereoscopic microscope.

Results

The results of the analysis yielded no evidence of ostracodes in the sediment samples, suggesting that the chemistry of water retained by the reservoir did not favor their growth.[4] However, an unanticipated source of information was recovered from auger units 2, 3, and 5 in the form of well-preserved uncarbonized seeds of the aquatic plant *Lemna*, commonly known as duckweed. Seed frequencies ranged from 0 in the gravel deposits (and the control sample) to 62 in the medium and fine alluvium. Relative frequencies vary among the samples, and it is noteworthy that seeds are most abundant in the deeply buried, finer sediments (i.e., those deposited near the base of the prehistoric reservoir).

Seed Description

The archaeological population of *Lemna* seeds from the reservoir has a fairly uniform morphology. The seeds are ellipsoidal to ovoid, with a surface sculpture consisting of a series of widely spaced vertical ribs connected by numerous closely spaced transverse ridges that create a reticulate effect (Figure 3). A bump or operculum of variable prominence is present at one end. Dimensions obtained include a mean length of .5 mm and a mean diameter of .3 mm. Rib counts are estimated to be less than 20, as attempts to count them resulted in the collapse or fragmentation of the fragile specimens. Anastomosing of some of the ribs also was observed (Figure 3).[5] All of the specimens are empty seed coats as the embryos apparently disintegrated long ago. The seeds are bleached white.

Duckweeds are members of the Lemnaceae, a family that in Arizona consists of three genera characterized as small plants that float on or in

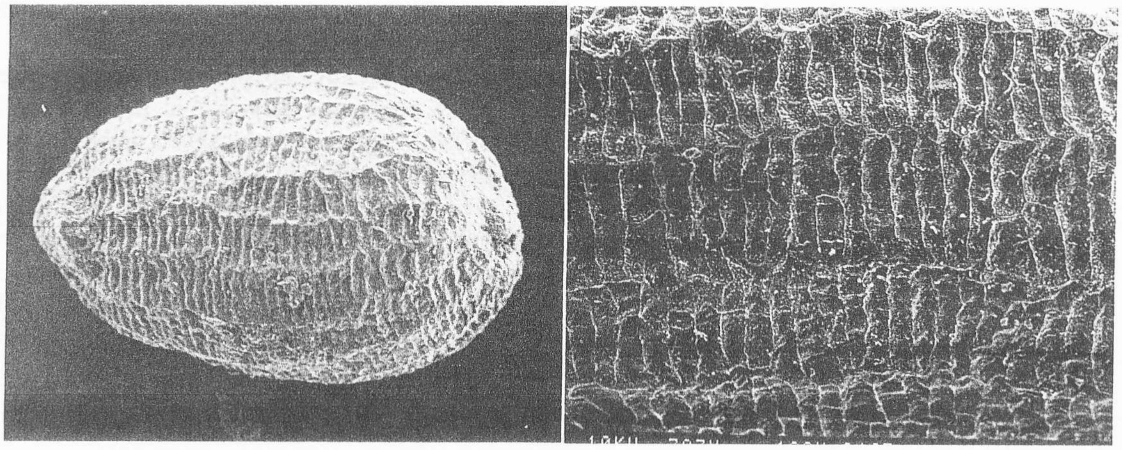

Figure 3. Left, scanning electron photomicrograph of *Lemna* seed (×131). Note the operculum at left end. Right, scanning electron photomicrograph of reticulate surface of *Lemna* seed (×383). Photomicrographs by Lisa Huckell.

still or slowly moving fresh water (Landolt 1992). Duckweed plants flourish in stagnant small ponds, pools, or ditches that are rich in organic matter (Hillman 1961:231). *Lemna* plants consist of small, round to elongated, root-bearing, leaflike structures called fronds that seldom exceed 15 mm in their longest dimension. Reproduction is accomplished both vegetatively and, less frequently, through the production of seeds. Flowering usually occurs in the late spring and early summer; the resulting fruit is a utricle that contains one to six seeds (Mason 1957:327–335; Landolt 1992).

Identification of the archaeological seeds beyond the genus level is not possible from the seeds alone, as insufficient systematic investigation has been done on the family's seeds. Rib counts, the only feature consistently mentioned in the literature, are equivocal because species' ranges tend to overlap (Landolt 1992). However, flowering and fruiting habits suggest two species as likely candidates, because five of the seven Arizona species rarely produce seeds (Landolt 1992). The two flowering species, *L. aequinoctialis* Welwitsch (formerly included in *L. perpusilla* Torrey) and *L. gibba* L., have been documented as flowering frequently and fruiting most freely under natural conditions (Hillman 1961:234; Landolt 1992). Limited examples of fruiting specimens in the holdings of the University of Arizona Herbarium for *L. aequinoctialis* (UAH 139429) and *L. gibba* (UAH 161920) indicate that the seeds of both taxa are essentially identical and fall within the range of forms found within the archaeological assemblage as well. It should be noted that the sample may consist of multiple species.

Seed Preservation

The recovery of uncarbonized seeds was unexpected. When looking at plant remains from cultural contexts, most investigators use carbonization as the main criterion for associating items with human activity (Minnis 1981). However, other factors and agents preserve noncarbonized plant remains, such as waterlogging and mineral replacement (Bold 1967:63; Green 1979; Miksicek 1983, 1987). Microscopic (9 to 150×) examination of the *Lemna* seeds reveals a fragile-looking, spongy testa composed of two obvious layers that are reduced to a single layer in the operculum, a seemingly unlikely candidate for preservation.

High concentrations of calcium carbonate in the soils and water of this part of the Southwest are well known. To test for the presence of calcium carbonate in the *Lemna* seeds, we immersed one of them in a 10 percent solution of hydrochloric acid; no reaction occurred, indicating its absence. Future treatment of the seeds with substance-specific biological stains (Berlyn and Miksche 1976:89) may reveal some constituents of the seed coat, indicating whether the cellulose contains silica, suberin, or another substance that would increase its durability.

The possibility of postabandonment introduction of the seeds into this Classic-period reservoir appears unlikely for several reasons. First and foremost, the seeds were found in an appropriate stratigraphic context based on the seed-producing behavior of the genus; the medium-to-fine alluvial sediments in which the seeds occur are those that would be expected to form the floor of the active reservoir. The absence of seeds from the coarse sediments in the uppermost deposits of the reservoir suggests that this fill is derived from the postabandonment collapse and erosion of the reservoir embankments. This condition quite likely precluded the maintenance of the environment in which a large *Lemna* population could flourish. Finally, the absence of insect exoskeletal elements (particularly those of seed-gathering ants) from the sediments suggests that bioturbation from this common source played little or no role in the introduction of seeds into the deeply buried reservoir deposits.

Context of Seed Production

We offer an explanation for the presence of *Lemna* seeds in the lower portions of the reservoir sediments that is based on these provisional species identifications. Seed production in both *Lemna* taxa (*L. aequinoctialis* and *L. gibba*) is a response mechanism to low temperatures and drought. This particular response is uncommon among many duckweed species; most species use a strategy of specialized vegetative reproduction in which starch-rich, morphologically distinctive fronds (turions) are created that sink to the bottom of a water source (e.g., reservoir) and remain embedded in mud until favorable growth conditions return. Fruits may float or sink, with seeds germinating either at the surface or below it (Hillman 1961:234–235).

The extraordinary numbers of seeds recovered from some of the reservoir sediments (Table 1) suggest that populations of *Lemna*, some of which must have been extensive, produced seeds in substantial quantities during periods of environmental stress, perhaps low temperatures or low water level. Whether seasonally low temperatures (winter) or low water levels (summer) account for episodes of seed production in high numbers is impossible to ascertain conclusively at present. Both *Lemna* species prefer locations in direct sunlight (Hillman 1961:232), which lends weight to the low-temperature hypothesis.

The alternative possibility of low water levels at the prehistoric reservoir at site AZ AA:3:32 (ASM) seems less plausible, given the documented capability of a nearby earthen stock pond to hold water year-round (Bayman 1993; Bayman and Fish 1992). In either case, the presence of seeds from an aquatic plant (i.e., *Lemna*) in a Hohokam reservoir is direct evidence that these features retained water for a significant portion of an annual cycle.

Discussion and Conclusion

The recovery of *Lemna* seeds has important implications for the duration of water storage in Hohokam reservoirs as well as the preservation of botanical remains in archaeological sites. Regardless of the conditions that enabled duckweed seeds to survive, their presence offers proof that noncarbonized plant remains can preserve—and can be recovered from—reservoir sediments that are at least 700 years old. The recovery of these seeds complements additional plant taxa reported from four excavated Hohokam reservoirs (Barber 1983; Ciolek-Torrello 1987; Dart 1983; Fish 1983). Two of these reservoirs contain pollen from an aquatic plant (Cyperaceae) (Fish 1983:601), in addition to macrobotanical remains and pollen from local desert taxa and cultigens (e.g., *Zea*).

Further evidence for long-term water storage in Hohokam reservoirs was acquired by the recovery of an aquatic mud turtle (*Kinosternon* sp.) at Gu Achi, a large Preclassic-period reservoir site (AZ Z:12:12 [ASM]) in the nonriverine desert west of Phoenix and Tucson (Johnson 1980:363). The recovery of common reed (*Phragmites*) at this site also implies that water was stored at Gu Achi on a long-term basis (Gasser 1980:323). Although human consumption of water was a pressing need[6], and most certainly led to the construction of an earthen reservoir at Gu Achi, common reeds and other biological resources that thrive in well-watered environments were also economically valuable.[7]

Given the data available thus far, we expect that even more floral and faunal taxa that flourish in water-rich environments remain to be discovered in Hohokam reservoirs. Such data are vital. Sediment samples from other reservoirs may reveal ancillary evidence (e.g., phytoliths, pollen, diatoms, snails[8]) that bear directly on the issue of water storage duration. To further test and strengthen our hypothesis that Hohokam reservoirs were capable of long-term water storage, acquisition of such information is essential. Methods suggested here also should prove useful in other desert regions where reservoir technology was part of the economy.

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Notes

1. Additional reservoirs with Preclassic or undated components (not shown in this figure) are listed in Bayman (1993:146–147). Temporal classification of all reservoirs was based on ceramic types listed in site records on file at the Arizona State Museum or in published reports.

2. Noncomparable formulas have been used to estimate the maximum volume of water storage reservoirs in the Southwest (e.g., Dart 1983; Scarborough 1988) and elsewhere (Kennedy 1995). Nonetheless, a study by Scarborough (1988) convincingly demonstrates that Hohokam reservoirs are relatively large compared to reservoirs found in other regions of the Southwest.

3. Direct analogy between modern stock ponds ("cattle tanks") and Hohokam reservoirs is fraught with potential complications. Nonetheless, many modern stock ponds (cattle tanks) and Hohokam reservoirs are roughly comparable in morphology and size, are located in similar topographic settings, and therefore provide some insight into methods of landscape engineering devised for the Sonoran Desert.

4. Possible reasons for a lack of ostracode microfossils in some archaeological contexts are outlined in Palacios-Fest (1994).

5. The scanning electron microscope we used is an International Scientific Instruments model DS130. The dried seeds required no pretreatment and were mounted on aluminum stubs with double-sided tape. All specimens were sputter-coated with 30 nm of gold and examined at 20 kV.

6. Although water in Hohokam reservoirs was probably sometimes used for pot irrigation of nearby cultigens, domestic consumption of water seems more plausible and was perhaps more common. Two lines of evidence support this interpretation: (1) several excavations of Hohokam reservoirs have yielded evidence of intake channels for capturing runoff but no outlets for delivering water to agricultural fields (e.g., Ciolek-Torrello and Nials 1987; Dart 1983:457, 467–469); (2) analysis of botanical remains from one reservoir at site NA18,022 (MNA) failed to produce any remains of cultigens (Ciolek-Torrello and Nials 1987:290).

7. Rea (1983:61–75) lists a variety of bird and vegetation species that are "riparian analogs" for the Gila River valley watershed. In addition to reflecting a well-watered environment, many of these species would have been economically useful in prehistory. Water in the Gu Achi reservoir might have attracted an occasional migratory fowl, a supplementary foodstuff for the Hohokam (Masse 1980:196). Consumption of larvae and insects from reservoirs has been inferred for Precolumbian Mesoamerica (Angulo 1993:165), and such resources probably were harvested from reservoirs in the Sonoran Desert. Tule stems from Mesoamerican reservoirs were used to weave mats and baskets (Angulo 1993:165), and the Phragmites reeds from Gu Achi could have been used by the Hohokam in a similar fashion or as kindling or fuel for starting fires (Gasser 1980:323).

8. Two species of land snails (Hawaiia miniscula and Succinea avara) have been reported from flotation samples recovered from a Hohokam reservoir (Barber 1983). Although these are not aquatic species, their presence in contexts in and near the reservoir suggests that they were attracted to the abundant moisture (Barber 1983:622).

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