The Paleoecology and Archaeology of Long-Term Water Storage in a Hohokam Reservoir, Southwestern Arizona, U.S.A.

James M. Bayman,[1] Manuel R. Palacios-Fest,[2] Suzanne K. Fish,[3] and Lisa W. Huckell[4]

[1]*Department of Anthropology, University of Hawaii, Honolulu, Hawaii 96822*
[2]*Terra Nostra Earth Sciences Research, Tucson, Arizona 85741*
[3]*Arizona State Museum, Tucson, Arizona 85701*
[4]*Maxwell Museum of Anthropology, Albuquerque, New Mexico 87131*

Water storage reservoirs were an important feature of economic organization among ancient societies in the North American Southwest. Analyses of reservoir sediments from a Hohokam archaeological site in the Sonoran Desert yielded taxonomic species of ostracodes (microscopic crustaceans) and pollen grains that are indicative of a past water-rich environment. The discovery that this reservoir was capable of storing water on a long-term basis indicates that archaeological models for the region, which have relied on direct historic analogy, must be reexamined. In contrast to the local ethnographic record, paleoecological data generated by this study imply that the Hohokam could establish permanent desert settlements with water storage reservoirs away from perennial rivers and streams. Moreover, residents of these areas were geographically positioned to facilitate the circulation of marine resources (i.e., salt and shell) from the Gulf of California to territories within and beyond the Hohokam region. © 2004 Wiley Periodicals, Inc.

INTRODUCTION

The Hohokam archaeological record reflects one of the most spectacular societies in the North American Southwest prior to Spanish contact in A.D. 1540. The Hohokam practiced agricultural production, lived in pit houses and surface pueblos, and crafted a variety of goods including (but not limited to) fired-clay figures and ceramic vessels, plant fiber textiles, stone projectile points, and marine shell ornaments (Haury, 1976). In the latter part of the developmental sequence, Hohokam settlements typically surrounded monumental buildings such as ball-courts in the pre-Classic period (ca. A.D. 1–1150), and platform mounds in the Classic period (ca. A.D. 1150–1450) (e.g., Wilcox and Sternberg, 1983; Doyel, 1991; Fish and Fish, 1991; Wilcox, 1991).

The Hohokam are probably best known for the concentration of large-scale irrigation canals and associated sites in the Salt-Gila River valleys of the Phoenix Basin. This area also witnessed the greatest elaboration of material culture and the most intensive construction of monumental architecture. Since many of the earliest archaeological excavations took place at sites along large canals (e.g., Gladwin,

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1928; Schroeder, 1940), many archaeologists refer to the Phoenix Basin as the Hohokam "heartland" or "core" (e.g., Haury, 1976). Areas without large canals, to the south and west of Phoenix and Tucson, comprised one portion of the Hohokam "periphery" Hohokam (see McGuire [1991] for an extended discussion). The area was named the Papagueria ("land of the Papago people") by early Spanish explorers and missionaries who colonized the region in the 16th and 17th centuries.

This core-periphery perspective has been greatly refined over the past 20 years, with the unexpected discovery of large habitation settlements and evidence of agriculture in areas away from major streams and rivers (e.g., Fish et al., 1992). Moreover, a growing number of water storage reservoirs have been documented in the so-called periphery (e.g., Raab, 1975; Antieau, 1981; Wilcox and Sternberg, 1983; Bayman, 1993). Interpretations of Hohokam subsistence and settlement in the periphery are often based on the implicit assumption that reservoirs were non-perennial sources of water. This inference is solely derived by direct historic analogy with the "two-village" settlement system of the historic Tohono O'odham (formerly Papago) Indians (cf. Gasser, 1979).

Some ethnographic accounts (e.g., Underhill, 1939; Castetter and Bell, 1942:42–43), for example, describe Tohono O'odham people who occupied lowland summer villages and relied on earthen reservoirs for storing water. Following the end of the summer rains, reservoirs were no longer recharged with surface flow and villages in the uplands were reoccupied during winter, where water was retrieved from excavated wells and springs. Archaeologists working in the Papagueria often surmise that ancient Hohokam communities practiced a similar strategy of residential mobility and lived in different settlements during the dry and wet seasons of the year.

In this paper, we evaluate paleoecological data from a Hohokam reservoir at a large archaeological site in Organ Pipe Cactus National Monument in southwestern Arizona. Analyses of sediments from the reservoir document the occurrence of ostracodes and pollen that are indicative of a water-rich environment during the Hohokam use of this facility. Although the volume of water in the reservoir would have certainly fluctuated on a seasonal basis, indications of permanent water imply that some Hohokam could occupy this lowland settlement on a year-round basis.

After we outline paleoecological evidence of this phenomenon, we conclude our discussion by exploring key implications of our findings for archaeological interpretations of ancient economic organization in the periphery. First, however, we provide a brief background on the geography, ecology, and archaeology of the reservoir and its associated site within the broader context of Organ Pipe Cactus National Monument.

BACKGROUND

Geography and Ecology

Organ Pipe Cactus National Monument is in southern Arizona and borders the Mexican state of Sonora. Most of the monument lies within the Arizona Upland subdivision of the Sonoran Desert (Shreve, 1951; Turner and Brown, 1982; see also Felger et al., 1997). The monument grounds encompass an area of approximately 133,830 hectares (Felger et al., 1997), limited to the south by the United States–Mexico border, on the east by the Tohono O'Odham Nation, on the north by the town of Ajo, and on the west by the Cabeza Prieta National Wildlife Refuge (Figure 1). The climate is typically arid, and the monument lies on the eastern edge of the driest region of the United States and in the general area of highest temperatures (Felger et al., 1997). Mean winter temperature is 15°C (December, January, February) with occasional overnight temperatures below 0°C and summer mean temperatures over 40°C (June, July, August). Precipitation is about 180 mm/year with rainfall occurring in two seasons, winter and summer (Dodge, 1964). Effective moisture is quite low, given the combination of high temperatures and low rainfall.

The monument area consists of gently sloping alluvial plains and well-dissected mountains that characterize the Basin and Range Physiographic Province. The alluvial plains consist of eroded sediments derived from the volcanic and plutonic rocks that form the surrounding mountains (e.g. Ajo Mts., Bates Mts.) (Brown and Johnson, 1983; Kresan, 1997). The unconsolidated gravels, sands, silts and clays are extremely variable. In general, their poor sorting and roundness reflect proximity to the source rock and high energy of the depositing stream. Sedimentary limestone outside the park is the most likely source of tufa in the alluvium within the reservoir.

Coates (1952) indicates that groundwater in the area is almost entirely derived from rainfall originating in the mountains and transported through stream channels which recharge the aquifers. The average depth of the aquifers is approximately 23 m. In a few restricted locales there are springs (e.g., Quitobaquito Springs) that are fed by the aquifers rather than surface flow (Kresan, 1997).

In terms of the dispersed, shrub-dominant vegetation, triangle-leaf bursage (*Ambrosia deltoidea*) and creosotebush (*Larrea tridentata*) are the dominant species in the monument, followed by ocotillo (*Fouquieria spendens*), saguaro (*Carnegiea giganteca*), chain fruit and buckhorn cholla cacti (*Opuntia* spp.). Crucifixion thorn (*Castela emoryi*) is restricted to the lowlands, far from the mountains. Most areas have mesquite trees (*Prosopis*), a few Palo Verde trees (*Cercidium* spp.), organ pipe cactus (*Stenocereus thurberi*) and prickly pear (*Opuntia* spp.), along the flanks of the mountains and hills. Other plants common in the vicinity include jojoba, brittle-bush, annual buckwheat and hedgehog, pencil cholla and Christmas cacti.

The reservoir that we examined for this study is located within a large Hohokam archaeological site (State No. AZ Z:13:1). This site is located about 20 km south of the town of Ajo, in the north-central portion of Organ Pipe Cactus National Monument (Figure 1). This geographic locale comprises only one small part of the rich archaeological record of south-central Arizona and its neighboring environs in Sonora, Mexico.

Figure 1. The location of Organ Pipe Cactus National Monument in southwestern Arizona (from Rankin, 1995:2).

Regional Archaeology

The most up-to-date summary of the archaeological record at the monument is based on a large-scale pedestrian survey by the Western Archeological Center, United States National Park Service (Rankin, 1995). Areas of the monument examined by Rankin (1995) contain archaeological sites spanning a vast period of time that ranges from the Early Archaic (8500 B.C.) through the historic period (ca. A.D. 1900). Cultural traditions identified in the monument include the southwestern Archaic (8500 B.C. to A.D. 150), the Hohokam, Patayan, and Trincheras prehistoric ceramic cultures (A.D. 300–1450), and Hia C'ed O'odham (formerly "Sand Papago") of the post-Spanish period (Rankin, 1995:xxiv).

Material remains of these cultures include artifacts of stone, ceramic, and marine shell; and a variety of archaeological features including "sleeping circles," rock rings, roasting pits, hearths, pit-house structures, refuse deposits, and at least one ditch or small "canal." Some of the larger sites are the remains of habitation settlements, whereas many smaller sites signify task-specific resource extraction activities including plant processing, animal butchering, quarrying of stone, and the production of rock art including petroglyphs (pecked) and pictographs (painted). A number of rock shelters, bedrock mortars, and foot trails are also present in the monument.

Only one of 178 sites recorded on the survey has an earthen reservoir, archaeological site AZ Z:13:1 [ASM] (Rankin, 1995). This site was once a large Hohokam habitation settlement that covers approximately 260 acres (105 ha). In addition to a reservoir, this archaeological site (AZ Z:13:1 [ASM]) also has remnants of numerous pit houses, roasting pits, deflated refuse mounds, and scatters of artifacts (Rankin, 1995:181). One pit houses exposed by erosion revealed a charcoal filled hearth (Rankin, 1995:192). Surface evidence indicates that ground stone implements and tabular knives are also common, along with projectile points, bifaces, a stone "doughnut," and lots of plain and decorated ceramics. Notably, ceramic disk and modeled spindle whorls were also identified at the site, indicating the weaving of plant fibers. The small sizes of the spindle whorl apertures suggest the spinning of cotton (Rankin, 1995:182). Obsidian and marine shell artifacts are also present on the site surface, in addition to fragments of turquoise or azurite. Decorated ceramics at the site indicate that it was occupied during the Sedentary (A.D. 975–1150) and Classic periods (A.D. 1150–1400) of the Hohokam chronological sequence (Rankin, 1995:181).

Previous archaeological excavations of Hohokam sites with this degree of surface artifact diversity have always been proven to be permanent habitation sites (see Huntington and Teague, 1984:183). Thus, as Rankin (1995) aptly notes, site AZ Z:13:1 [ASM] is remarkable in several respects. The discovery of an ancient site in this desert locale, with all of the hallmarks of a sedentary village, was unexpected, since water for domestic consumption would have seemingly been scarce. There are no springs nearby, and the site is located many kilometers from the nearest mountain range where such springs might be located. The nearest perennial river (i.e., Gila) is located approximately 100 km from the reservoir site. Thus, the construction and use of an earthen reservoir at site AZ Z:13:1 (ASM) was an important factor of human settlement in this arid region.

The Ancient Reservoir

The largest and most visible feature at the site is an earthen reservoir that required a considerable investment of labor to construct and maintain. It is currently comprised of three oval embankments that cover an area with an approximate diameter of 35 m (Figure 2). Together, these embankments form a C-shaped mound

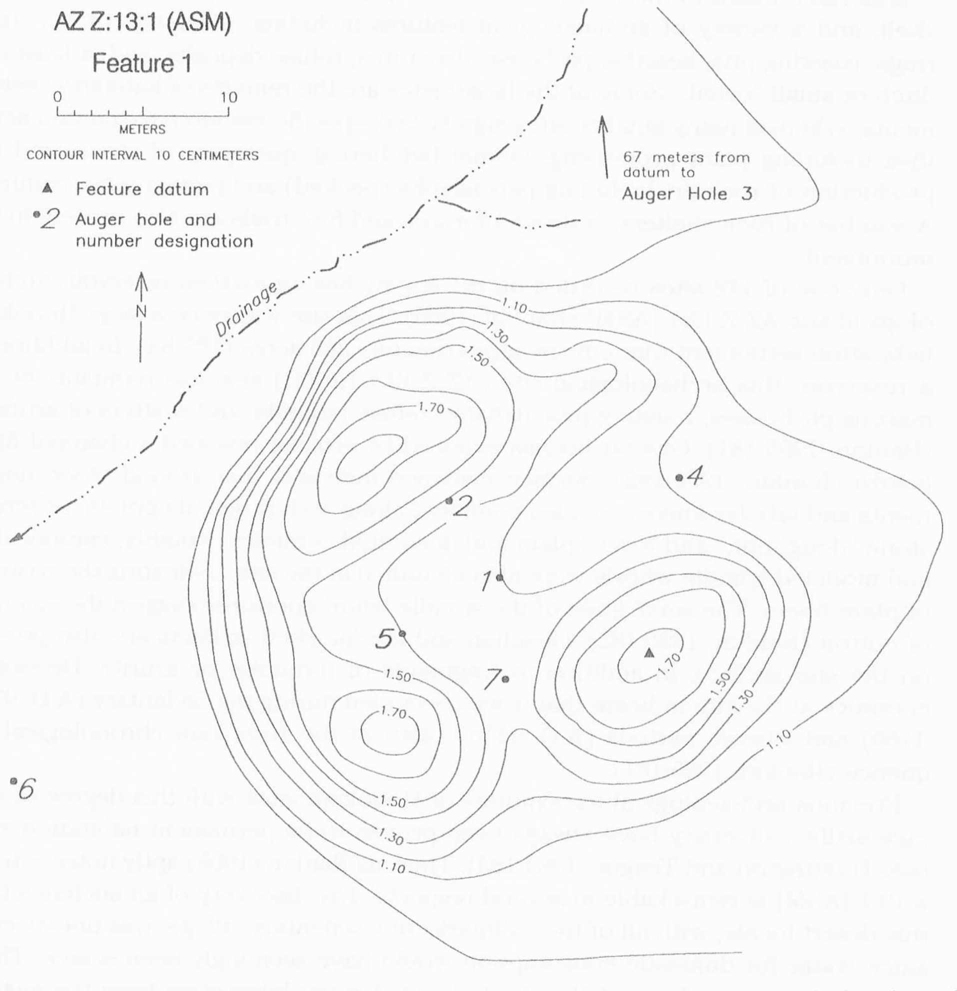


Figure 2. Contour map of the reservoir at archaeological site AZ Z:13:1 [ASM]. Note the locations of auger holes.

that encompasses a shallow basin filled with fine alluvium. An intake channel for the reservoir is located north and east of the C-shaped mound; it is currently filled with alluvium (Figure 2).

Augering of the reservoir (discussed below) indicated that its maximum depth is currently about 2.80 m below the ground surface. This is a significant finding, since a 20th century inventory of Tohono O'odham charcos (reservoirs) by the United States Indian Service concluded that reservoirs between 8 and 10 ft deep held water on a perennial basis (Clotts, 1915:22). If the embankments of the Organ Pipe reservoir are conservatively estimated to have been a meter higher than they are today, it was once almost 4 m in depth. In short, during prehistory, the Organ Pipe reservoir significantly exceeded the depth of perennial reservoirs observed by Clotts (1915:78).

Thus, it is not surprising that the Organ Pipe reservoir embankments are littered with a high number of ceramic sherds, flaked stone artifacts, fire-cracked rock, vesicular basalt grinding tools (*manos* and *metates*), and broken marine shell. Formal ground stone tools of vesicular basalt were evidently imported since material for manufacturing them is not available at the site. The abundance of ground stone artifacts indicates that seed and corn processing took place at this settlement.

PALEOECOLOGICAL ANALYSES

This study was designed to reconstruct the paleoecology of the reservoir at the time it was used by the Hohokam. The major goal of this research was to determine whether the reservoir was a perennial, or seasonal, source of water. In order to reconstruct the reservoir paleoecology, analyses were conducted on ostracodes, pollen, and wood charcoal.

Sample Recovery and Extraction

Samples of sediment were acquired from vertical columns in the reservoir deposits using a hand-driven auger with a 3.5-in. bucket. A total of seven auger columns were taken, with locations selected to obtain samples from a horizontal cross-section of the reservoir, and from different depths and areas of the water storage facility. The five auger columns within and atop the reservoir embankments (OP-1, 2, 4, 5, and 7) were strategically placed in areas that enabled us to document the overall morphology and depth of the feature (Figure 2). Two additional auger columns (OP-3 and OP-6) were placed outside the reservoir to provide controls for evaluating the abundance (or lack) of paleoecological remains in the other auger interior columns (Figure 2).

During the deployment of the auger, observations for each column sample were recorded including lithological characteristics and whether charcoal and plant debris were present (Figure 3). Sediments were also described using Munsell color charts, to monitor vertical changes in stratigraphy along each auger column. This information was vital for identifying samples that were most likely to contain intact ostracodes. Since ostracodes are relatively fragile and friable and pollen is subject

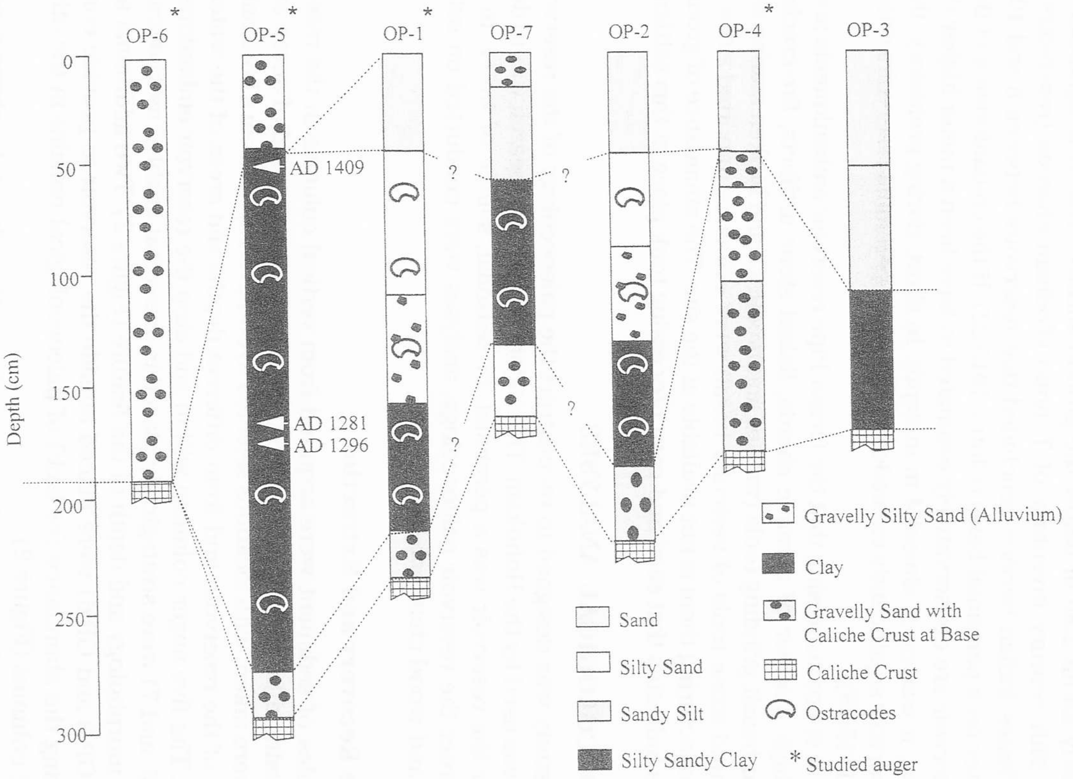


Figure 3. Stratigraphic profile of the auger columns in the reservoir. Note the vertical locations of ostracodes. The profile of OP-5 shows the location of radiocarbon age-estimations.

to oxidation, we avoided samples with coarse, gravelly sediments and large pore spaces. Clay deposits, for example, are more likely to contain well-preserved ostracodes and pollen (Figure 3). The analyses of the auger column sediments were also focused on examining samples from a horizontal cross-section of the reservoir, and from different depths and areas of the water storage feature.

Clay deposits were, in fact, present in auger columns OP-1 and OP-5, indicating that these locales were favorable for the preservation of ostracodes (Figure 3). The thickest clay deposit (2.40 m) was located in auger column OP-1, near the reservoir center. Tufa was also mixed with the clay deposits. A thinner clay deposit (0.59 m) with tufa was located in auger column OP-5, near the presumed "shoreline" of the reservoir. No clay was observed in samples from auger OP-4, near the mouth of the reservoir. These samples also contained gravel, sand, and silt. Samples from OP-6 were examined to provide an analytical control, since this auger was located outside the reservoir. This core contained alluvial gravel, sand, and silt.

Samples from augers OP-2 and OP-7 were not processed to extract biological materials. However, their lithologic properties (i.e., the presence of clay) indicate that ostracodes and pollen are likely to be present. Although these samples were not examined for ostracodes, the depth of these auger samples yielded useful information on construction of the reservoir.

Ostracode Extraction and Identification

Samples from auger columns OP-1, OP-4, and OP-5 were processed to determine whether ostracodes were present and sufficiently preserved to be taxonomically identified. Sediment samples from auger control column OP-6, located outside the reservoir, were also examined for comparison with samples examined from the reservoir. About 40 g of sediment from each sample was processed following the routine freeze-thaw technique developed by Forester (1991) and modified and refined by Palacios-Fest (1994, 1997a, 1997b).

A total of 95 discrete samples were examined for ostracodes, using a low-power stereoscopic microscope. Of the 95 samples, no fewer than 33 contained identifiable ostracodes. Taphonomic features (abrasion, fragmentation, encrustation, coating, carapace/valve and adult/juvenile ratios, and a redox index) of each specimen were recorded to establish the paleoecological conditions of the reservoir.

The population of ostracodes that inhabited the reservoir was monospecific, consisting only of *Heterocypris antilliensis* (Figure 4). With few exceptions (i.e., Nevada), this species is seldom documented in the American Southwest (Forester, personal communication, 1999) and it is most commonly found in the Caribbean. All fossiliferous samples were characterized by a relatively low abundance ($n = 1–249$) of specimens. *Heterocypris antilliensis* ranges in size from 800 to 1000 mm, and it commonly occurs in springs and seeps comprised of diverse hydrochemical compositions (Forester, 1991). It is an eurythermic (11 to $> 30°C$) and euryhaline species (~ 750 to > 4000 μS/cm). A key characteristic of this genus is its ability to grow under strong temperature and chemical gradients (e.g., San Luis Hot Springs, Colorado; St. David Springs, Arizona) (Forester, 1991).

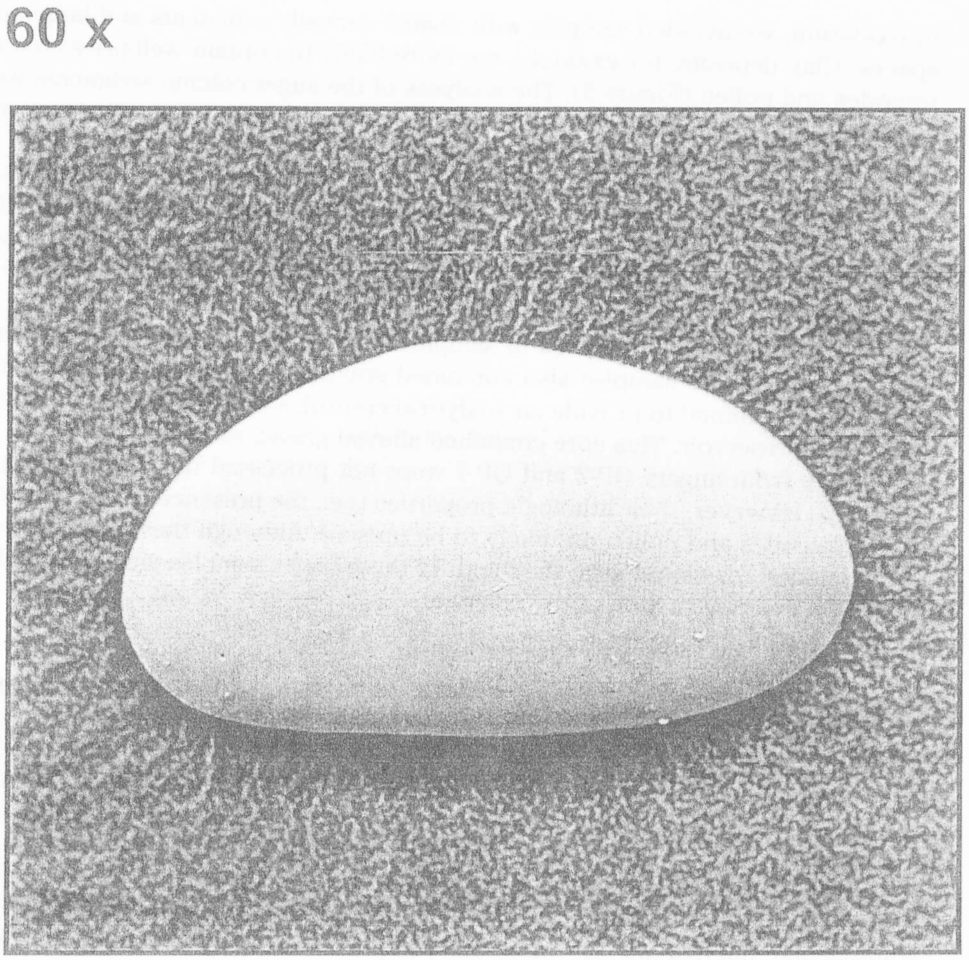


Figure 4. Scanning electron microscope (SEM) image of one of the *Heterocypris antilliensis* (Broodbakker, 1982) ostracodes recovered from the reservoir auger samples at site AZ Z:13:1 (ASM).

Figures 5 and 6 illustrate the proportions of different taphonomic, paleoecological, and paleontological features for *Heterocypris antilliensis*. Fragmentation varies from low (< 10%) to extremely high (> 90%), abrasion and encrustation are moderately low (15–40%), coating is low (< 20%), and the redox index shows slight oxidation of valves. The carapace/valve ratio indicates extremely high rate of disarticulation of the valves. The adult/juvenile ratio shows dominance of adults throughout the record.

Auger column OP-1 mostly contains valves of adult ostracodes. However, auger OP-5 is notable for its abundance of juveniles, indicating that adult ostracodes did

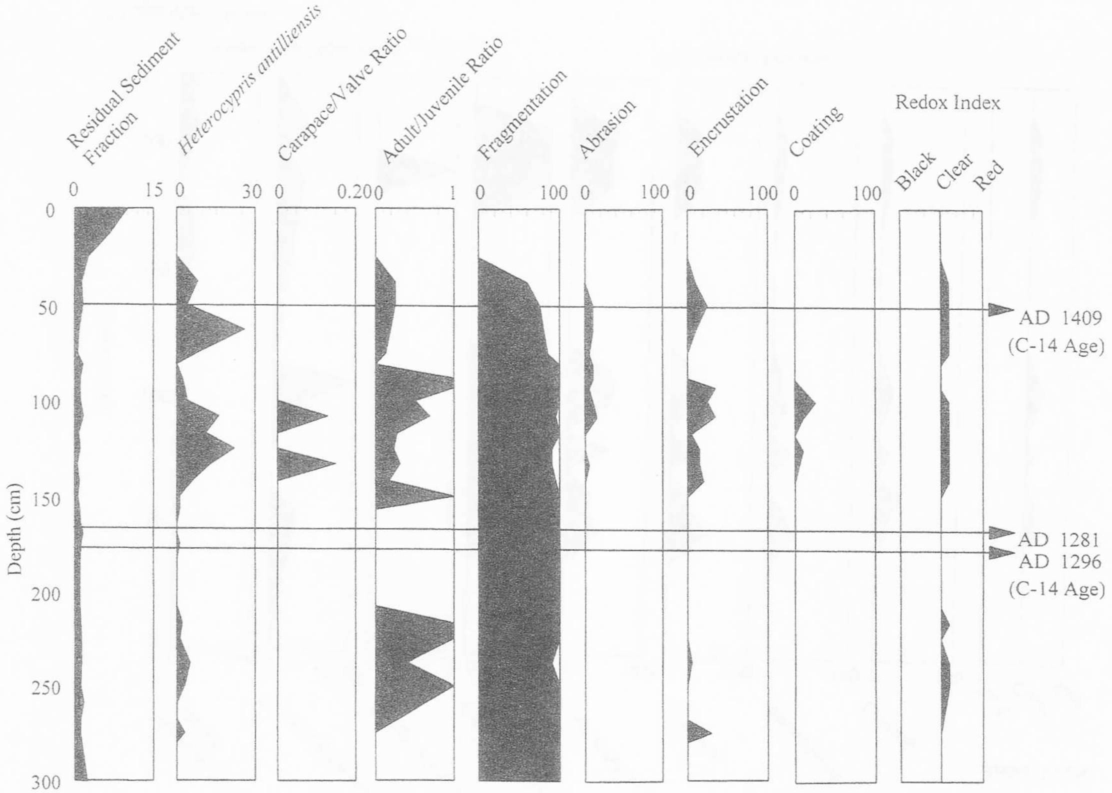
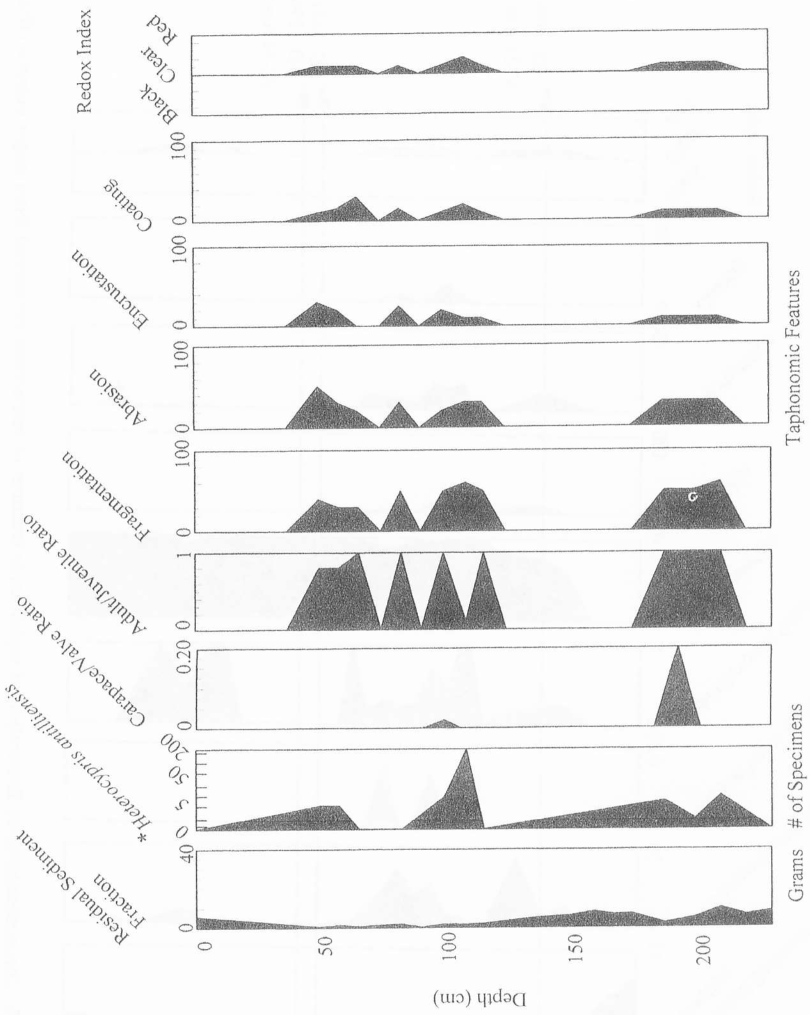


Figure 5. Chronostratigraphic illustration of taphonomic features of ostracodes recovered from auger column OP-5. Note the vertical location of radiocarbon age estimations.



* Logarithmic Scale

Figure 6. Chronostratigraphic illustration of taphonomic features of ostracodes recovered from auger column OP-1.

molt successfully and complete their life-cycle in the deeper parts of the reservoir. Moreover, they likely foraged on aquatic plants near the water surface. Biological reproduction probably also took place in this area. Angell and Hancock (1989) have demonstrated that *Heterocypris* lays eggs and cement them to a suitable substrate like grass stems or leaf litter. Therefore, it is conceivable that upon maturity, *antilliensis* migrated from deeper areas of the reservoir to shallow vegetated portions of the reservoir.

Since the life-cycle of *Heterocypris* is estimated to be no less than 3 months (Broodbakker, 1982, 1983), and perhaps longer, surface water was evidently present in the reservoir for a considerable period of time. The large size of some of adult ostracodes further underscores the effectiveness of this facility for storing water. A study of pollen from the reservoir sediment samples was undertaken to provide an independent assessment of ostracode data.

Pollen Identification

Due to the different extraction methods used for ostracodes and pollen, separate portions of each sediment sample were set aside for pollen analysis. Thus, pollen data were acquired for the same auger columns that were examined for ostracodes. This procedure was followed to integrate data from the two studies. Pollen was preserved in all samples, with identification of 200 grains in each case (Fish, 2002a, 2002b). The predominant pollen types reflect shrubby and herbaceous species of desert vegetation resembling that of the present site locale. Although a wide variety of pollen was identified, two taxa were especially relevant to evaluating the duration of water in the Hohokam reservoir.

Cattail (*Typha* sp.) pollen was found sporadically from auger samples that range in depth from 63 cm to 275 cm. Since cattail requires permanently damp soil, its presence in the auger samples indicates that water was present in the reservoir year-round. Indeed, cattail has been documented at natural wetlands (e.g., springs and marshes [*cienegas*]) and water-holding bedrock depressions (*tinajas*) throughout the Papagueria (Felger, 2000:24–26). Except during the most extreme drought years, some of these oases yield water on a perennial basis (Felger, 2000:26, 562). Cattail seeds are reportedly viable for many years, and once a wetland is recharged with water, it is likely to reemerge (Felger, 2000:562).

The vertical distribution of cattail pollen across more than 2 m of the reservoir auger columns confirms that cattail was present at the reservoir for much of its life history. Since cattail grows in water as deep a 1 m (Felger, 2000:562), it would have grown along the edges of the ancient reservoir. To produce pollen at reproductive maturity in the spring, the plants must have been sustained by wet conditions over the preceding year. Although cattail could be introduced repeatedly to the reservoir by wind or biological agents (e.g., birds, people), its generally consistent presence in the reservoir samples affirms that this facility was a moisture-rich environment on a recurring year-round basis.

Sedge (*Cyperaceae*) pollen is also distributed among the reservoir sediment samples. However, since sedge can grow in seasonally damp soil, it is not as strong an indicator of year-round water storage. Although sedge offers only a weak signature, its presence does point toward the persistence of moisture or water in the reservoir. What remains to be answered, therefore, is whether water from the reservoir was used to water plants, or used only for human consumption. The broken ceramic vessels found on the reservoir embankments were possibly used to transport water to other locales within or beyond the archaeological site.

Notably, no pollen of cultigens (or any other pollen signature indicating subsistence remains) was observed in the reservoir samples. However, pollen from cultigens is often rare in Hohokam reservoirs (e.g., Fish, 1983:598–603; Ciolek-Torrello and Nials, 1987:290), and thus failure to recover it in these samples is not conclusive. Indeed, this absence may also reflect ancient efforts to keep the reservoir and its immediate environs free of refuse and debris, since it provided a critical supply of water. As recently as the 1980s, contemporary Tohono O'odham Indians were witnessed burning weeds and other vegetation that obstructs surface flow to their reservoirs (Nabhan, 1982:28).

Although pollen from cultigens was not encountered in the reservoir samples, other pollen types suggest that agriculture on some scale was potentially practiced near the reservoir. Samples recovered below 63 cm, likely deposited during site occupation, yielded chenopod and amaranth (*cheno-am*) pollen in greater frequencies than samples from the upper levels, likely deposited during postoccupational filling. Because chenopods and amaranths proliferate in the weedy flora of culturally modified environs, cheno-am pollen is typically abundant in the sediments of Southwestern archaeological sites. Pollen of a suite of three additional weedy plants was also present in the reservoir samples: spiderling (*Boerhaavia*-type), globe mallow (*Sphaeralcea* spp.), and Arizona poppy (*Kallstroemia* spp.). Elevated frequencies of these three are an indicator of land disturbance in ancient agricultural fields associated with Hohokam occupations elsewhere in southern Arizona (Fish, 1985, 1994). All these weedy species also may reflect non-agricultural activities at settlements that disturbed and enriched the soil, such as pit house construction and refuse disposal.

In short, pollen from the reservoir corroborates the evidence for a past water-rich environment that was detected with the ostracodes. Together, these lines of evidence support the hypothesis that the reservoir was a reliable source of water for residents of the ancient village. However, the chronological period(s) when the reservoir was used were uncertain, although decorated ceramics were present on the site surface. Although the Hohokam ceramic chronology is relatively well developed (see Dean, 1991), estimating the age of the reservoir with surface ceramics is fraught with uncertainty. Fortunately, plant charcoal was recovered from the auger column samples. This charcoal was taxonomically identified and used to acquire independent age-estimations of the reservoir via radiocarbon assays.

Charcoal Identification and Radiocarbon Age-Estimation

Samples from auger column OP-5 were examined for the presence of plant macrofossils. Relatively little plant material was present in the sediments, except for a small number of carbonized wood charcoal fragments. Four samples of wood charcoal from auger column OP-5 were selected for taxonomic identification and radiocarbon dating (Table I). All of the samples were dicotyledonous wood; just two could be identified further as possible mesquite/acacia (cf. Prosopis/Acacia), both of which are locally available aborescent legumes.

The ranges of the age estimations at 2 standard deviations (Table I) indicate that the charcoal samples were burned sometime between the early 13th and mid-15th centuries. In terms of the Hohokam chronology, these burning events evidently took place during the Classic period.

Nonetheless, one of the charcoal age-estimations (i.e., OP-5-5[2]) from the reservoir samples is arguably problematic, since it was recovered only 50 cm below the surface of the reservoir, and yet it produced the earliest age-estimation (Table I). However, the plant genus for this sample was unidentifiable, whereas the samples that produced younger age estimations (i.e., OP-5-5, OP-5-19, and OP-5-20[1]) were derived from mesquite (*Prosopis*), a common tree in the vicinity of the reservoir today. Thus, it is possible that the charcoal sample that produced an anomalously early date (i.e., OP-5-5[2]), given its relatively shallow stratigraphic location, was derived from "old wood." The Sonoran Desert's xeric climate promotes the exceptional preservation of dead, decay-resistant woods (mesquite among them) for decades and even centuries, resulting in an easily gathered fuel wood supply. Consequently, age estimations from samples of "old wood" may yield dates that are much earlier than the archaeological event of interest (Schiffer, 1986).

Alternatively, it is plausible that Hohokam maintenance and operation of the reservoir altered the vertical distribution of sediments and charcoal in this facility. Periodic "dredging" of the reservoir was possibly undertaken by the Hohokam to enlarge its water storage capacity as human population of the settlement increased, or as the reservoir became clogged with alluvium and plant detritus. In fact, the relatively high fragmentation and abrasion of ostracode valves does indicate that

Table I. Radiocarbon age estimations for reservoir charcoal samples.[a]

Site No.	Auger Sample	^{14}C Age yr B.P.	Calibrated Age yrs A.D.	Calibrated A.D. Range at 2 Stand. Dev. (Maximum & Minimum of Calibrated Age Estimations)
AA37120	OP-5-5	753 ± 38	1278	1217–1297
AA37121	OP-5-5(2)	539 ± 38	1409	1316–1439
AA37122	OP-5-19	736 ± 37	1281	1223–1376
AA37123	OP-5-20	679 ± 66	1296	1223–1408

[a] The age estimations calibrations were produced using Stuiver and Reimer's (1993) CALIB Program (Version 4.2).

this feature was periodically disturbed, perhaps by efforts to clean and maintain its embankments. Moreover, postoccupational bioturbation may have transported small fragments of charcoal above or below their initial provenance in the reservoir.

In spite of these potential problems, radiocarbon age-estimations strongly suggest that the reservoir was constructed and used during the Classic period. Interestingly, decorated ceramics on the surface of the site indicate that this locale (if not the reservoir) was also utilized in some fashion during the Preclassic period (Rankin, 1995). The adoption of reservoir technology in this desert locale in the Classic period has important implications for archaeological models of Hohokam economic organization.

DISCUSSION

Studies of the reservoirs' paleoecology confirm that it was an effective device for capturing and storing surface runoff on a perennial basis. The ostracode analyses indicate that water was present in the reservoir for no less than 3 months, and probably much longer. The species of ostracode (i.e., *Heterocypris antilliensis*) that was recovered from the reservoir requires no less than 3 months to reach a stage of maturity sufficient to produce offspring and to molt, thus completing its life-cycle (Brookbakker, 1983). The evidence that this took place confirms that the watershed surrounding the reservoir supplied sufficient water for the development of juvenile ostracodes into adults.

Indeed, the large size of the adult ostracodes implies that water for encouraging their growth and development was present for more than three months. The presence of cattail pollen (*Typha*) provides stronger evidence that water was present within the reservoir on a long-term basis. Although the total volume of water must have fluctuated within an annual cycle, it would have been quickly recharged by diverted sheetwash during the winter and summer rainy seasons of the Sonoran Desert. While ostracodes confirm the presence of water in the reservoir for no less than 3 months, the cattail (*Typha*) pollen illustrates that some water was present on a year-round basis. *Typha* flourishes in natural and artificial wetlands throughout the Sonoran Desert (Felger, 2000:562; Felger et al., 1992), and its presence in an ancient reservoir is a significant and unprecedented finding in Hohokam archaeology.

This newly recovered data complements previously documented aquatic and semiaquatic botanical and faunal remains at other archaeological sites with reservoirs in the Sonoran Desert (Table II). These remains include seeds and pollen from a variety of plants, as well as the remains of a mud turtle. Together, these data strongly imply that Hohokam reservoirs were reliable sources of water.

ARCHAEOLOGICAL IMPLICATIONS

The conclusion that the reservoir was capable of storing water on a long-term basis has profound implications for the archaeology of Organ Pipe Cactus National Monument, and the broader Hohokam territory. Archaeological models of Hoho-

Table II. Aquatic and semiaquatic biological remains documented from Hohokam reservoir sites.

State No. and/or Site Name	Biological Remains	Hohokam Period of Occupation	References
AZ Z:13:1 (ASM)	Cattail (*Typha*) pollen	Classic & Late Preclassic	This paper
AZ Z:13:1 (ASM)	Ostracodes (*Heterocypris*)	Classic	This paper
AZ Z:13:1 (ASM)	Sedge (*Cyperaceae*) pollen	Classic	This paper
AZ U:15:98 (ASM) Pool 98	Sedge (*Cyperaceae*) pollen	Classic & Preclassic	Fish (1983:600–601)
AZ U:14:73 (ASM) Smiley's Well	Sedge (*Cyperaceae*) pollen	Classic & Preclassic	Fish (1983:599)
AZ AA:3:32 (ASM)	Duckweek (*Lemna*) seeds	Late Classic	Bayman et al. (1997)
Gu Achi AZ Z:12:13 (ASM)	Reeds (*Phragmites*)	Preclassic	Gasser (1980:323)
Gu Achi AZ Z:12:13 (ASM)	Mud turtle (*Kinosternon* sp.)	Preclassic	Johnson (1980:363)

kam land use and economic organization often draw a contrast between the so-called "core" and "periphery" (e.g., Haury, 1976; Wilcox and Sternberg, 1983; Gregory, 1991; Masse, 1991; McGuire, 1991). In such models, Hohokam culture was centered in a dense concentration of communities with large-scale irrigation canals along the Salt and Gila rivers in the Phoenix Basin. Settlements in these core communities relied on intensive agriculture that was enriched by foraging in the nonriverine desert (Masse, 1991). In contrast, outlying communities away from perennial streams practiced less intensive forms of agriculture, since large-scale canal irrigation was not feasible in remote desert areas (e.g., Fish et al., 1992).

Ethnographic sources indicate that 19th and 20th century Tohono O'odham Indians constructed water storage reservoirs in areas of the periphery that were formerly occupied by the Hohokam (e.g., Underhill, 1939; Castetter and Bell, 1942). Moreover, Tohono O'odham occupied these valley-bottom settlements for only part of each year (i.e., spring and summer) until the reservoirs dried in the early fall. This pattern of residential mobility is sometimes called a "two village" settlement system. With the onset of winter, members of these reservoir villages typically relocated to vacant settlements near mountain springs, or wells that were drilled by the United States government (Underhill, 1939; Castetter and Bell, 1942).

The uncritical application of this ethnographic model by some archaeologists has led them to conclude that communities in the periphery were also relatively mobile (e.g., Haury, 1976), and followed a "two village" settlement system (e.g., Rosenthal et al., 1978:216–219; Masse, 1991:201). This two-village settlement system was necessary, it is argued, because reservoirs were nonperennial sources of water. The recent discovery that some Hohokam reservoirs were capable of storing water on a long-term basis (Bayman and Fish, 1992; Bayman, 1993; Bayman et al., 1997) indicates that archaeological interpretations of ancient residential mobility must be reconsidered (Bayman, 1997). The unqualified application of ethnographic models that are derived from historic-period accounts of the Tohono O'odham is clearly inappropriate for interpreting the Hohokam (Doyel, 1991; Fish and Fish, 1991; Fish and Nabhan, 1991). Indigenous populations in the Papagueria were almost certainly less mobile than many archaeologists once believed (Hartmann and Thurtle, 2001:513).

Moreover, mobility is often construed by archaeologists as a behavioral phenomenon that precludes any degree of residential sedentism. In the Papagueria, however, it is likely that some members of Hohokam habitation settlements engaged in nonlocal resource procurement (e.g., hunting and foraging) in the fall and spring, much like the historic-period Tohono O'odham (Castetter and Bell, 1942). By contrast, other members of these habitation settlements would have stayed behind to continue their involvement in the planting and harvest of crops, production of marine shell ornaments, and other economic endeavors. In such a scenario, the departure of some residents during periods of relatively low precipitation (fall and spring) would have reduced the consumption of water in reservoirs, during a period when its volume temporarily diminished.

Ancient communities in the periphery must have served an important role in overseeing the circulation of marine shell and salt from coasts along the Gulf of California, in Sonora, Mexico. These valued resources were transported to settlements in the Phoenix Basin core and elsewhere in the North American Southwest through systems of circulation that would have included barter and the payment of debt, damages, and brideprice (Bayman, 1997). Direct participation in the marine shell economy by populations in the so-called periphery would have greatly strengthened their social identity and economic role in relation to other communities in the Sonoran Desert (Bayman, 2002). Rather than being passive "dependents" of more powerful Hohokam in the Phoenix Basin (see McGuire and Howard [1987], for example), communities in the periphery were engaged in advancing their own interests and agendas. Identifying the sociopolitical consequences of this phenomenon must become a priority of contemporary research in the Arizona desert (Bayman, 2001).

CONCLUSION

This project was pioneering in Sonoran Desert archaeology with respect to its analytical methods. Archaeological studies of ancient reservoirs in southern Arizona have failed to fully investigate their economic functions in Hohokam society. This project is unique in its emphasis on recovering and analyzing a suite of biological remains (e.g., ostracodes, pollen, charcoal) to test a specific scientific hypothesis, namely, that Hohokam reservoirs were capable of storing water on a long-term basis in the Sonoran Desert. The interdisciplinary scope of this research and its integration of multiple lines of evidence has yielded valuable results for exploring this question. This research confirms that some, if not all, Hohokam reservoirs were capable of storing water on a year-round basis.

The studies conducted for this project provide the basis for additional investigations that could further refine our understanding of the paleoecology of Hohokam reservoirs. Ostracode stable isotopes and trace elements could be measured and interpreted, and diatoms could be extracted and identified from reservoir sediments. Examination of these materials would offer a rich corpus of information for further assessing the chemical conditions and biological signatures of water storage in Hohokam reservoirs. In the meantime, this study of ostracodes, pollen, and charcoal has provided valuable insights on the performance of one reservoir in the Hohokam periphery. The information generated by this study also provides a firm foundation for developing new methods to examine the longevity and economic implications of ancient water storage technology.

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