PALEOECOLOGY OF AN EARTHEN RESERVOIR IN ORGAN PIPE CACTUS NATIONAL MONUMENT
Evidence of Hohokam reservoirs in southwestern Arizona is abundant but little studied in terms of their distribution and history of use (Bayman 1993, 1997; Bayman and Fish 1992; Bayman et al. 1997). Part of the lack of attention is due to the fact that reservoirs are difficult to identify from the surface and, even when found, are best studied through a suite of paleoenvironmental analyses that require a diverse set of analytical skills and substantial financial support. Yet survival in the Sonoran Desert, particularly in the Papaguería, required detailed knowledge of water sources, whether natural or human-made (see Chapter 28 of this volume). Preliminary analysis of reservoirs indicates that the Hohokam were able to store water year-round by capturing seasonal surface runoff. The findings suggest that reservoirs were an important part of human strategies to survive in the desert and that archaeologists would do well to understand their history and characteristics.

The goal of this study is to reconstruct the paleoenvironmental history of a Hohokam reservoir on the basis of the ostracode and pollen records recovered from site AZ Z:13:1 (ASM) in Organ Pipe Cactus National Monument (OPCNM) (Figure 57). The presence of microinvertebrates and aquatic plant remains is a strong indication of water permanence in human-made reservoirs. For example, ostracodes (microcrustaceans, described below) are characterized by life cycles closely related to water permanence. Similarly, aquatic plants like cattail (Typha) and duckweed (Lemna) are commonly associated with long-term water bodies. The occurrence of either of these organisms, and particularly their co-occurrence, provide solid evidence of the properties of the reservoir and offer routes for the interpretation of anthropogenic impact.

The Hohokam reservoir documented herein provides a rare opportunity to understand water management in the past. We use the combination of sediment composition, ostracode abundance and assemblages, and the abundance of aquatic pollen to develop several working hypotheses on water source and on how long the reservoir was in use. We begin the chapter with an overview of the paleoenvironmental and archaeological context of the region. We discuss the significance of ostracodes and pollen in geoarchaeological research, as well as their salient ecological and biological features. We also describe the study area and summarize the regional archaeology. In the next major section, we present research methods and our results at the reservoir. Included are field and laboratory procedures for sampling sediments for ostracodes and pollen. The Results subsection documents the sediment composition relevant to the biological remains, the absolute dates, and the ostracode and pollen composition. In the final major section, we discuss the paleoenvironmental and archaeological implications of our findings. We reconstruct the paleoenvironment and propose two main hypotheses: one based on seasonal and one on permanent water storage. The latter hypothesis consists of three potential alternatives. We evaluate these hypotheses with respect to the evidence that we found and discuss the implications of the strongest alternatives.

**PALEOECOLOGICAL AND ARCHAEOLOGICAL CONTEXT**

**Significance of Ostracodes and Pollen in Prehistoric Aquatic Systems**

Geoarchaeological research on ostracodes is useful for reconstructing the environment where ancient peoples of the Southwest lived. Palacios-Fest (1994, 1996, 1997b) and Palacios-Fest et al. (2001) demonstrated that ostracodes in irrigation canals leave traces of the seasonal intake of water and its discharge to agricultural fields. Such studies have also been undertaken in other archaeological regions. Bradbury et al. (1990), for example, studied ostracode assemblages associated with irrigation systems in Belize during the Classic Maya period. More recently, Machain-Castillo et al. (1992) conducted a paleoenvironmental study in the Maya tropical landscape using ostracodes. Shortly thereafter, Hodell et al. (1995) and Curtis et al. (1998) reconstructed the environment where the Classic Maya civilization developed and presented ostracode evidence for possible ecological sources of its collapse.

Continental water ostracodes can live in a variety of conditions ranging from very restricted (stenotopic) to widely variable (eurytopic) environments (Delorme 1969, 1989). These arthropods molt their skeletons as many as nine times during their life cycle.
Figure 57. Location map of Organ Pipe Cactus National Monument, the landscape within which site AZ Z:13:1 (ASM) lies.
form a calcium carbonate shell that preserves in the geologic record; they typically range from 0.5 to 2 mm in size (Horne et al. 2002; Pokorny 1978). These organisms are also highly adaptive and may live in ephemeral or permanent surface waters (Forester 1991; Smith and Horne 2002). This environmental flexibility allows different species of ostracodes to reach maturity in either a short time (e.g., approximately 4 weeks for *Limnocythere staplini* (Richard Forester, personal communication 1988) or a long time (e.g., approximately 1 year in low latitudes for *Darwinula stevensoni*) (Smith and Horne 2002). The species found in this study, *Heterocypris an tillens*, requires about 3 months to complete its life cycle.

Many projects have included the analysis of pollen as a component of prehistoric canals and reservoirs (Adams et al. 2002); results include some unpublished reports (Gish 1978, 1979; Schoenwetter 1978). Reports on historical-period canals are also available (Fish 1986). Records from prehistoric canals are far more abundant than those from reservoirs. Bohrer (1970) was among the very first to examine pollen from ancient canals. Since then, palynologists have analyzed more than 200 pollen samples from dozens of prehistoric Hohokam canals. Numerous studies of water-control features such as canals, reservoirs, and drainage ditches have provided diverse information on the paleoecology of aquatic systems. For example, some of these features have contained cultigen pollen considered to have originated in associated Hohokam fields (Fish 1987; Lytle-Webb 1981; McLaughlin 1976; Nials and Fish 1988); a similar pattern has been observed elsewhere in the world (Puleston 1977; Wiseman 1983, 1990). Fish (1994) demonstrated that the season of deposition can be recognized from the presence of upland pollen in water-control systems. She suggested that water sources may be discriminated, as well. Riparian vegetation like cattails and sedges can become established in canals and reservoirs through pollen dispersal either from plants growing nearby or from long-distance sources via moving water (Fish 1994).

**Study Area**

Site AZ Z:13:1 (ASM) is situated in the north-central portion of OPCNM, 20 km due south of Ajo. OPCNM is in far south-central Arizona, bordering the state of Sonora, Mexico (see Figure 57). The park encompasses 330,170 acres (Felger et al. 1997), north of the United States—Mexico border, west of the Tohono O’odham Nation’s reservation, south of Ajo, and east of Cabeza Prieta National Wildlife Refuge. Most of the park lies within the Arizona Uplands subdivision of the Sonoran Desert (Shreve 1951; see also Felger et al. 1997; Turner and Brown 1982). The climate is arid—the study area lies at the eastern edge of the region of the United States that is driest and has some of the highest temperatures (see Felger et al. 1997; Rankin et al., this volume). During the winter, mean temperature is 15°C; overnight temperatures occasionally fall below 0°C. Summer mean temperature sometimes exceeds 40°C. Precipitation averages 180 mm per year; rainfall shows a biseasonal winter and summer pattern (Dodge 1964). The combination of high temperatures and low rainfall results in low effective moisture.

The area consists of gently sloping alluvial plains and heavily dissected mountains in the Basin and Range Physiographic Province. The alluvial plains consist of sediments eroded from the volcanic and plutonic rocks that form the surrounding mountains (e.g., Ajo Mountains, Bates Mountains) (Brown and Johnson 1983; Kresan 1997). These unconsolidated gravels, sands, silts, and clays are extremely variable. In general, the poor sorting and roundness of sediments reflect their proximity to the source rock and high energy of the depositing stream. Coates (1952) reported that groundwater in the area is solely a function of rainfall, mostly from the mountains. Multiple stream channels contribute to recharging the aquifers. Today, the average depth of the aquifers is about 23 m (Tim Tibbits, personal communication 1999). Kresan (1997), however, suggested that the water in Quitobaquito Springs (southern edge of OPCNM) is of local origin and not highly dependent on local precipitation.

About 15 percent of the park’s surface is covered with vegetation. Triangle (triangle-leaf) bur sage (*Ambrosia deltoidea*) and creosotebush (*Larrea tridentata*) are the dominant species and are accompanied by ocotillo (*Fouquieria splendens*), saguaro (*Carnegiea gigantea*), and jumping and buckhorn cholla cacti
The Paleoeconomy of an Earthen Reservoir in Organ Pipe Cactus National Monument

Regional Archaeology

Rankin (1995a) summarized archaeological information for the area. Human occupation dates from the Early Archaic (ca. 8500 B.C.) and extends to the historical period (ca. A.D. 1900). Cultural traditions identified in the OPCNM area include southwestern Archaic (8500 B.C.-A.D. 150), the Formative Hohokam, Patayan, and Trincheras cultures (A.D. 300-1450), and the Hia C-ed O’odham (formerly known as the “Sand Papago”) of the post-Spanish period (Rankin 1995a:xxiv).

Of the 178 sites recorded on Rankin’s (1995a) survey, only one has an earthen reservoir: archaeological site AZ Z:13:1 (ASM). This site contains a large Hohokam settlement that covers an area of 260 acres. Archaeological features include a reservoir as well as numerous pit houses, roasting pits, deflated refuse mounds, and scatters of artifacts (Rankin 1995a:181). Decorated ceramics indicate that the site was occupied by Hohokam communities during the Sedentary (A.D. 975-1150) and Classic (A.D. 1150-1400) periods (Rankin 1995a:181).

THE RESERVOIR

The unexpected finding of a habitation village at site AZ Z:13:1 (ASM) is remarkable because of the scarcity of water in the area (Rankin 1995a). No springs are present nearby, and the nearest mountain range where such springs might be located is several kilometers away. The Gila River, the nearest perennial river, lies approximately 100 km to the north. Thus, the finding of a reservoir, which is a relatively rare archaeological feature, was not as surprising as it would be elsewhere in the Hohokam region.

The reservoir currently consists of three oval embankments that cover an area with an approximate diameter of 35 m (Figures 58 and 59). The reservoir has a well-defined C shape that encompasses a shallow basin filled with alluvium. Its opening is oriented upslope to the northeast (see Figure 58, inset).

Ceramic sherds, flaked stone artifacts, fire-cracked rock, vesicular basalt grinding tools (manos and metates), and broken marine shell litter the reservoir embankments. Vesicular basalt grinding tools were evidently imported—this material is not available at the site. The abundance of these artifacts indicates that seed and corn processing was an important activity.

Sampling the Reservoir

To collect samples for the various studies, we chose to auger the reservoir. Augering is a minimally destructive and cost-effective technique for recovering sediment samples from archaeological deposits (Stein 1986). We used a steel hand-driven bucket auger (with a head 10 cm long) to obtain reservoir sediments. Samples were collected at 25-cm intervals to the bottom of the reservoir.

We collected seven hand-auger cores, five from the reservoir and two from reference locales (see Figure 58, inset), ranging in length from 160 to 300 cm (Figure 60). Auger cores OP-1, OP-4, and OP-5 were examined to identify and extract ostracodes; OP-5 was also analyzed for pollen content. Auger core OP-6, taken outside the reservoir, was analyzed as a control sample. All cores ended at a hard petrocalcic crust that the auger could not penetrate.

We drew two subsamples from each sample: one for ostracode analysis and another one for pollen analysis. We processed about 40 g of sediment from each sample interval, using the routine freeze-thaw technique of Forester (1991) as modified by Palacios-Fest (1994). We conducted routine micropaleontological analysis on 56 samples, using a low-power stereoscopic microscope. Taphonomic features (abrasion, fragmentation, encrustation, coating, disarticulation and adulthood ratios, and a redox index—an index of staining of the valves) were recorded to establish the paleoecological conditions of the reservoir (Figure 61).
We processed about 20 g of sediment from the same horizons (from auger core OP-5) for pollen analysis, using standard procedures for such extraction (Fish 1983). In order to permit calculation of pollen concentration, we added one *Lycopodium* tablet (13,911 spores per tablet) to each sample before processing. We counted a minimum of one entire microscope slide (22 by 22 mm) per sample. This technique resulted in a pollen sum (total count of grains per slide) of as many as 300 “upland” (i.e., nonaquatic) pollen grains. The pollen concentration in g per cm³ was calculated from the pollen sum.

Results

Most of the sediments at AZ Z:13:1 (ASM) probably accumulated during the Hohokam Classic period between A.D. 1300 ± 66 and A.D. 1425 ± 38 (Table 6). Four radiocarbon samples from OP-5 yielded dates consistent with the Classic period ceramic artifacts that are present on the site. One of these dates appeared to be a reverse age from old carbon (see Table 6); therefore, it was discarded from subsequent analyses (for a total of three dates shown in Figures 60 and 61). A few pre-Classic ceramics are also present at the
site, though it is not clear if the reservoir was used during this period.

Of the 56 samples analyzed from all cores, 30 contained ostracodes. Thirty-two of the 33 samples (OP-5) analyzed for pollen contained enough grains to count (sample OP-5-5 was the only one with insufficient pollen).

The sedimentological record of the reservoir (see Figure 60) consists of fine sediments in the inner part of the reservoir. This area is characterized by Gilman series soils consisting of very deep, nearly level to gently sloping, stratified, alkaline, very fine sandy loam or loam (Hendricks 1985). The source materials include a variety of metamorphic, volcanic, and some sedimentary rocks from the surrounding mountains. In general, the lithology of the reservoir is consistent with the soil map for this part of the park (Soil Survey Staff 1972).

The reservoir's stratigraphy (see Figure 60) was revealed through auger cores OP-1, OP-4, OP-5, and OP-6. Within the reservoir, the surface sediments consisted of very pale brown (10YR 7/4, moist) sandy silt. The unit's thickness ranged from 13 cm at OP-5 to about 50 cm at OP-1. (Field descriptions indicate that OP-2 and OP-7 showed similar thicknesses.) Outside the reservoir, OP-6 consisted entirely of very pale brown (10YR 7/4, moist) sandy silt. OP-3 was similar to OP-6. Underlying the surface unit in OP-1 and OP-5 was a layer of fossiliferous, very pale brown (10YR 7/4, moist) to yellowish brown (10YR 5/4, moist) silty clay ranging in thickness from 25 to 225 cm. In OP-1, this layer was interrupted by a sandy silt lens around 83 cm below ground surface (bgs). OP-5, however, showed a sandy clay lens about 25 cm thick between the sandy silt and silty clay units. Field descriptions indicate that OP-2 and OP-7 showed the
Figure 60. Stratigraphic columns for auger holes drilled at AZ Z:13:1 (ASM). Auger holes marked with a star were analyzed for this study. The remaining cores were described in the field and correlated stratigraphically with the ones studied. The three radiocarbon dates obtained from OP-5 and used for further analysis (see Table 6) are indicated beside black arrows. Dates are cal A.D. ± 1σ. The ostracodes shown in the columns for OP-2 and OP-7 were inferred from the data, not observed (see text section “The Ostracodes”). Broken lines signify the stratigraphic correlations.

Table 6. Radiocarbon Dates for Organ Pipe Cactus National Monument AZ Z:13:1 (ASM)

<table>
<thead>
<tr>
<th>Laboratory ID No.</th>
<th>Sample ID No.</th>
<th>Depth (cm)</th>
<th>Material</th>
<th>δ¹³C</th>
<th>¹⁴C Age B.P. (1σ)</th>
<th>Cal A.D.</th>
<th>Cal A.D. Range at 2σ</th>
</tr>
</thead>
<tbody>
<tr>
<td>AA37120</td>
<td>OP-5-5(1)</td>
<td>50</td>
<td>unknown hardwood</td>
<td>-25.3</td>
<td>753 ± 38</td>
<td>1278</td>
<td>1217-1297</td>
</tr>
<tr>
<td>AA37121</td>
<td>OP-5-5(2)</td>
<td>50</td>
<td>mesquite/acacia</td>
<td>-22.1</td>
<td>539 ± 38</td>
<td>1409</td>
<td>1316-1439</td>
</tr>
<tr>
<td>AA37122</td>
<td>OP-5-19</td>
<td>164</td>
<td>unknown hardwood</td>
<td>-22.9</td>
<td>736 ± 37</td>
<td>1281</td>
<td>1223-1376</td>
</tr>
<tr>
<td>AA37123</td>
<td>OP-5-20(1)</td>
<td>170</td>
<td>mesquite/acacia</td>
<td>-22.8</td>
<td>679 ± 66</td>
<td>1296</td>
<td>1223-1408</td>
</tr>
</tbody>
</table>

Note: Radiocarbon dates were calibrated by Suwier and Pearson's (1998) method. The cal A.D. age for sample AA37120 appears to be a reverse age from old carbon. It is considerably different from sample AA37121, which is from the same core depth. Also, it was taken from an unknown hardwood, rather than a known genus or pair or genera (sample AA37121). Therefore, we discarded AA37120 from subsequent analyses, leaving a total of three radiocarbon dates.

*Values for cal A.D. range at 2σ are minimum-maximum age estimations.
Figure 61. Ostracode paleoecology as indicated by data from two auger cores: (a) OP-1; (b) OP-5. Figure 61a includes total abundance of *Heterocypris antillensis* and its relationship with sediment composition, as well as with the taphonomic variables used for the paleoenvironmental reconstruction of the reservoir. In addition to these characteristics, Figure 61b includes the position of the three radiocarbon dates obtained from plant material and used for further analysis (see Table 6). Dates are cal A.D. ± 1σ.
silty clay stratum underlying the sandy silt unit; in OP-2, this layer was interrupted by a sandy clay lens about 35 cm thick. At the reservoir's mouth, OP-4, in contrast, did not show the fine-sediment units. A yellowish brown (10YR 5/4, moist) silty sand stratum about 75 cm thick underlay the sandy silt unit. Underlying the silty clay stratum at OP-1 was a unit of yellowish brown (10YR 5/4, moist) sandy silt. The upper 75 cm of this unit was unfossiliferous; the 42 cm (188-230 cm bgs) below it contained fossils. The silty clay layer in OP-5, in contrast, was underlain by a unit of fossiliferous, yellowish brown (10YR 5/4, moist) sandy clay. At OP-4, an unfossiliferous layer of yellowish brown (10YR 5/4, moist) sandy silt with caliche underlay the silty sand unit. Sandy silt with caliche lay at the bases of auger cores OP-2 and OP-7, as indicated by field descriptions. All auger cores ended at a caliche crust that could not be penetrated.

The Ostracodes
Auger core OP-5, near the center of the reservoir, contained the thickest (240 cm thick) clay deposits with ostracodes and tufa (freshwater limestones usually formed around the mouths of hot or cold calcareous springs or along streams carrying large amounts of calcium carbonate in solution). At auger core OP-1, the deposit of sandy silt to calcareous sandy silt was 175 cm thick, interrupted by two strata of silty clay (about 25 and 10 cm thick, respectively) (see Figure 60). Three of the strata contained ostracodes and tufa. Auger core OP-4, at the mouth of the reservoir, consisted of unfossiliferous sandy silt to silty sand (alluvium) but lacked clay. Auger core OP-6, the reference core outside the reservoir, consisted entirely of sandy silt fan alluvium. The potential presence of ostracodes in auger cores OP-2 and OP-7 was inferred from the cores' lithological and sedimentological properties, as well as their similarity to auger cores OP-1 and OP-5. Auger cores OP-2 and OP-7 are not discussed further because they did not undergo detailed analysis.

The ostracode population consists entirely of *Heterocypris antillensis* (Broodbakker 1982). With a few exceptions, this Caribbean species is rarely found in the U.S. Southwest (e.g., Nevada) (Richard Forester, personal communication 1999). All fossiliferous samples were characterized by a relatively low abundance (1-249 specimens). *Heterocypris antillensis* ranges in size from 800 to 1,000 μm and usually is found in springs and seeps of diverse hydrochemical composition (Forester 1991). It is a eurythermic (11→30°C) and euryhaline (approximately 750→4,000 μS/cm) species with a life cycle that appears to last about 3 months (Broodbakker 1983). One main 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).

Hydrogeochemical analyses of alluvial basins in Arizona—including Quitobaquito Springs, Bonita Well (north of Quitobaquito), and Vekol Valley, the closest sites tested—indicate a sodium-bicarbonate-chloride- or sodium-sulfate-chloride-dominant composition; calcium is lost early along the flow path to precipitation into calcite (Carruth 1995; Robertson 1991) (see Figure 57). Carruth (1995) suggested that Quitobaquito Springs water is less than 2,000 years old, thus local in origin and probably derived from rainfall recharge along the surrounding Cipriano Hills and Puerto Blanco Mountains. The age of the Vekol Valley groundwater is unknown, but we can reasonably assume that it is also young water accumulating from rainfall recharge in the area of Table Top Mountain and the Vekol range (Robertson 1991). A similar assumption may be made with respect to the Growler Wash area, where the Bates and the Puerto Blanco Mountains are the recharge zones for this basin.

It is unclear if water chemistry has changed over the past 2,000 years from calcium-rich to calcium-depleted conditions, but water pathways reported from Quitobaquito Springs and Vekol Valley differ from the ideal conditions reported by Forester (1991) for *Heterocypris antillensis* in modern springs. Thus, the hydrochemical tolerance of *H. antillensis* may be extended to alkaline-rich and nonalkaline (chloride-rich) environments. Hence, *H. antillensis* must be a eurytopic species (one with broad environmental tolerance) useful for environmental reconstructions.

The paleontological and paleoecological diagrams for *H. antillensis* (see Figure 61) include taphonomic features. Fragmentation varied from low (< 10 percent) to extremely high (> 90 percent). Abrasion and
encrustation were moderately low (15–40 percent). Coating percentages were low (< 20 percent). The redox index showed slight oxidation of valves. The carapace to valve ratio indicated an extremely high degree of disarticulation of the valves. The adulthood ratios (1:1 to 1:6) showed that adults and juveniles shared the environment throughout the record. The paleoecological significance of these properties is presented in the Paleoecological and Archaeological Implications section, below.

**The Pollen**

Arboreal and nonarboreal pollen was recovered from OP-5. Bursage-type, mesquite, and palo verde pollen types originated from plants in the vicinity of AZ Z:13:1 (ASM). Pine (Pinus) pollen, which is airborne, is a component of regional pollen rain. Nonarboreal pollen was dominant. Cheno-am, composite (Asteraceae), spiderling (Boerhavia), and grass were the dominant nonarboreal types, characteristic of both local and extralocal vegetation (Adams et al. 2002). Aquatic pollen was also recovered from OP-5. Cattail pollen, for example, was found in the reservoir at a depth between 63 and 275 cm. This aquatic plant requires permanent water or soil moisture. Sedge (Cyperaceae) pollen was found in association with cattail pollen. Although neither plant was especially abundant, they both require standing water or moist soil.

The vertical distributions of cattail and sedge pollen across more than 2 m of the sedimentary column in the reservoir indicated long-term to permanent aquatic conditions. Because cattails live in water no deeper than 1 m (Felger 2000:562), they probably lived along the edge of the reservoir rather than in its deeper part. Cattails must have been growing in the reservoir because their pollen was present throughout the 2-m interval of the core associated with clay and ostracodes. No tetrad aggregates were found, however.

Sedge pollen was also common in the reservoir sediment samples. In contrast to cattails, sedges may grow in seasonally dampened soil; thus, they are not as strong indicators of permanent water storage. The presence of sedge pollen in the reservoir does not provide unequivocal support for the hypothesis that water was perennially present in the Hohokam reservoir.

A notable finding was the absence of pollen of cultigens or other economic plant resources (e.g., edibles) in the samples. Absence of cultigens, however, was not necessarily unexpected, because the Hohokam (and the contemporary Tohono O’odham) frequently cleaned the areas around canals or reservoirs to keep them free of refuse and debris (e.g., Ciolek-Torrello and Niâs 1987:290; Nabhan 1982a:28). The abundance of charcoal throughout the reservoir, especially below the 38-cm interval, may indicate episodes of reservoir cleaning.

The relative abundance of pollen of cheno-am, spiderling, globemallow (Sphaeralcea), and Arizona poppy (Kallstroemia) below the 63-cm horizon suggested that these species may have been important in the inhabitants’ diet and were encouraged in the area. Because these plants are native weeds that thrive in disturbed habitats, however, their abundance may be the result of the nearby water in the reservoir and vegetation clearance by humans.

In summary, pollen recovered from auger core OP-5 was consistent with the ostracode record for the reservoir. Both lines of evidence supported the hypothesis of long-term water storage at AZ Z:13:1 (ASM). These lines of evidence cannot tell us clearly if the site was used as a permanent residence or simply as a seasonal settlement.

**Paleoecological and Archaeological Implications**

On the basis of the sedimentological, biological, and taphonomic features recorded at AZ Z:13:1 (ASM) we propose four hypotheses to explain the origin of the reservoir, and we discuss their respective archaeological implications.

Under the first hypothesis, the Hohokam built these C-shaped structures to collect rainwater and runoff during the winter and summer rainy seasons and then stored it for several weeks to months. We would expect specific and mutually exclusive characteristics to support this seasonal hypothesis. Among these characteristics would be stratified, alternating coarse to fine sediments indicative of periods of runoff and desiccation. Clayey layers might show evidence of mud cracks in support of the desiccation episodes. High
rates of ostracode fragmentation, resulting from the high-energy flow of storm water, also would support this hypothesis. Given that juveniles of thin-shelled Heterocypris antillensis are even more fragile than adults, mostly adults should be recovered. Low pollen content from aquatic species would also indicate seasonal desiccation: the plants would not be able to maintain themselves in the long term if their habitat dried out too often; fewer plants would leave a lower volume of pollen.

The data gathered at the reservoir do not support the seasonal hypothesis. We found no evidence of alternating coarse and fine sediments, as would be expected from frequently interrupted storm runoff, in any of the three reservoir cores in the field or in the laboratory. In addition, the reservoir is more than 30 km from the main source of runoff, the Ajo Mountains (Brown and Johnson 1983; Kresan 1997) (see Figure 57). A small drainage passes just northwest of the reservoir; however, and it may have been diverted to fill the reservoir during Hohokam occupation. Additional evidence against the seasonal hypothesis was the absence of desiccation cracks. With respect to ostracodes, in contrast to the expected preponderance of adults, we primarily found the remains of juveniles, especially at OP-5; this result suggests the establishment of a biocenosis in the reservoir. Finally, cattail pollen is present throughout the fossiliferous interval, suggesting that these aquatic plants were well established in the reservoir.

The second and third hypotheses suggest a permanent source of water via a natural spring or a human-made well. Under the second hypothesis, the Hohokam built reservoirs to dam springs or seeps so that they could trap water on-site; under the third hypothesis, aware of the high water table, they dug wells (Crown 1987). Springs or wells commonly provided long-term water supplies along transportation routes, which were usually established to take advantage of water sources such as springs and tinajas. Reservoirs were probably built where such water sources were available.

A subtle line of evidence—the degree of redoximorphic features—may contribute to discriminating between the spring hypothesis and the well hypothesis. For example, springs mostly contain oxidized sediments because of the constant interaction of groundwater and atmospheric oxygen. In contrast, a well might contain reduced or slightly reduced sediments because the exchange of atmospheric and groundwater oxygen is not as intense. In addition, because of carbon dioxide atmospheric pressure, a spring-fed reservoir might contain tufa, especially in alkaline soils like the Gilman soil series present at OPCNM. In contrast, a well is not as likely to produce tufa, at least in the large quantities found in the reservoir.

For the most part, the data from AZ Z:13:1 (ASM) favor the spring hypothesis over the well hypothesis. The high content of tufa in auger cores OP-1 and OP-5 and the thickness of the fossiliferous deposit in the latter (indicating a continuous flow of well-oxygenated water) support the spring hypothesis. The abundance of ostracodes (and the 1:1 to 1:6 adulthood ratios) and the nearly continuous distribution of pollen from aquatic plants favor the spring hypothesis over the well hypothesis as well. The vertical walls of a well (especially if, as is probable, the users routinely cleared them) would have supported little if any vegetation. The result would have been low pollen deposition and few ostracodes (which depend on aquatic vegetation for survival). The pond formed by damming a spring, on the other hand, would have been a haven for both aquatic plants and ostracodes. The reservoir's embankments also suggest capitalization on a spring rather than excavation of a well: an embankment would be necessary for damming a spring or seep but unnecessary for containing a deeper well.

The only apparent inconsistency with the spring hypothesis is the topographic situation of the reservoir: it is very low in the bajada, and no springs away from the mountain fronts are reported in the literature. Neither Tim Tibbitts, research coordinator at OPCNM (personal communication 1999), nor Bryan (1922b) reported records of springs or seeps anywhere near the reservoir in historical time (last 150 years). Nonetheless, Tibbitts suspects that, before livestock overgrazing, the water table in the area was high, allowing the opening of seeps or springs in large drainages near the reservoir. Examples include Cuerda de Leña Wash and Growler/Cherioni Wash (less than 2 km to the northwest of the reservoir) (see Figure 57). In addition, the Bates Mountains seeps or Dripping Springs may have been connected
underground to the reservoir by means of the same aquifer system—they both are in the Ajo Valley watershed along Growler Wash (Robertson 1991) (see Figure 57).

The last of our four hypotheses is based on the observation that the reservoir was built on top of a petrocalcic layer (a bottom crust that cannot be penetrated with an auger). Was this layer a natural feature of the landscape? If so, were the builders aware of its existence, and did they build the reservoir above it deliberately, to take advantage of its water-retaining capacity? If not, did the Hohokam themselves build the layer so that they could perch water on top? During the course of our fieldwork, two of us (MP and JB) looked for but did not find evidence of masonry; therefore, we discard the possibility of a surface constructed to retain water. If the perched-water-table hypothesis holds, it relies on the "accidental" advantage of using naturally perched water that accumulates from runoff.

A perched water table might produce reduced sediments as the result of the poor oxic conditions characteristic of standing water systems. In consequence, a poorly oxygenated system of this kind might be unable to produce tufa despite the alkaline soils available. Most aquatic systems accumulate tufa along faults or under streamflow (e.g., Mono Lake [Greensmith 1989]; Hohokam irrigation canals [MP, personal observation]). The high tufa content in the auger cores analyzed, then, does not support the possibility of a perched water table. Microinvertebrates and pollen did not provide sufficient information to discriminate this hypothesis from any of the others.

Nevertheless, the perched-water-table hypothesis might be plausible despite the apparent difficulties of explaining oxidized sediments in a standing water system. Machette (1985) maintained that laterally flowing calcium-carbonate-rich groundwater commonly forms calcrite deposits such as the crust encountered at AZ Z:13:1 (ASM). If the petrocalcic layer was formed through a process similar to that suggested by Machette (1985), the water table may have been close to the surface at the time of Hohokam occupation, and damming perched water would have increased its volume for human consumption.

The hypotheses evaluated in this study were aimed at deciphering the use and stability of long-term water storage in the Southwest. Site AZ Z:13:1 (ASM) provides important information for understanding the use and operation of reservoirs by the Hohokam. The origin of this reservoir has profound implications for the archaeology of OPCNM. To date, OPCNM has been interpreted as a peripheral region (i.e., used seasonally or in transit, rather than for habitation) because it is away from perennial water sources (Fish et al. 1992). AZ Z:13:1 (ASM) probably is an exception to the rule because it hosted a long-term settlement around the reservoir. Such settlements may not have practiced agriculture as intensely as the "core" communities (Masse 1991), if at all. Instead, they may have relied on trade with travelers to obtain agricultural products. Bayman et al. (2004) presented several possibilities that might explain human occupation around the reservoir. The "two village" settlement system previously proposed (e.g., Masse 1991:201; Rosenthal, Brown, Severson, and Clonts 1978:216–219) is questioned on grounds of the recent discovery of several long-term reservoirs such as the one documented in this study (Bayman 1993; Bayman and Fish 1992; Bayman et al. 1997). The occupation of ancient communities in the periphery must have played an important role in trading goods with core communities like those of the Phoenix Basin. Rather than being passive "dependents" of more powerful Hohokam in the Phoenix Basin (see McGuire and Howard 1987), communities in the periphery were engaged in advancing their own interests and agendas. Recognition of the sociopolitical consequences of this phenomenon must become a priority of contemporary research in the Arizona desert (Bayman 2001, 2007).

**CONCLUSIONS**

The present study documented for the first time the presence of freshwater ostracodes, associated with long-term aquatic vegetation, in a Hohokam reservoir. The combination of sedimentological, faunal, and palynological signals contributed to addressing four hypotheses about the permanence of a reservoir at AZ Z:13:1 (ASM). The seasonal hypothesis has little supporting evidence, whereas
three groundwater hypotheses appear better supported. Of these, the sedimentological, biological, and taphonomic features examined support the spring hypothesis or possibly the perched-water-table hypothesis. This project was pioneering in Sonoran Desert archaeology as the first in which ostracodes were found in reservoirs and linked to archaeological interpretations. The research confirms that at least some Hohokam reservoirs were capable of storing water year-round.

On the basis of our results, we encourage others to pursue this line of research and to incorporate additional strategies, such as analysis of stable isotopes and trace elements in ostracode remains, to determine environmental conditions prevailing when these organisms lived in the area. The analysis of diatoms can provide additional information on the water chemistry during the operation of reservoirs.

ACKNOWLEDGMENTS

This research was partially supported by a grant from the Southwest Parks and Monuments Association. We sincerely appreciate the assistance of Tim Tibbitts, research coordinator at OPCNM. In addition to helping us auger the reservoir, Tim shared his rich knowledge of the natural history of the OPCNM area. We are also grateful for the support of our project by William Wells, superintendent of OPCNM. Finally, we thankfully acknowledge the spirited and skillful field assistance of Ron Beckwith and Steve Baumann, archaeologists with the Western Archeological and Conservation Center, National Park Service.