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ENVIRONMENTAL CHANGE IN THE WESTERN PORTION OF THE PAPAGUERÍA

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Adapt or perish, now as ever, is Nature's inexorable imperative.

—H. G. Wells

Understanding human occupation in southwestern Arizona requires an overview of the current and past conditions of the area. Environmental factors do not necessarily rule the course of human adaptation, but they do impose constraints and set parameters that affect people's lives and their use of resources. This chapter focuses on what we know about the present and past environmental characteristics of the western portion of the Papaguería. The chapter begins with a summary of the regional geology, geomorphology (soils and hydrology), climate, and biotic communities. Next, an overview of human adaptation to the changing environmental conditions of the Holocene is provided. The chapter ends with a few thoughts on the complicated relationship between human use and perception of the region known as the Papaguería.

ENVIRONMENTAL SUMMARY

Physiographic and Geologic Setting

The Papaguería is an area that is defined by geography, climate, plant communities, indigenous people, and archaeological cultures. The term "Papaguería," coined during the Spanish Mission period, refers to those lands occupied by O'odham speakers in southwestern Arizona, United States, and northwestern Sonora, Mexico—lands extending roughly from the Avra and Altar Valleys west of Tucson to the Gila Mountains east of Yuma, and from an area south of the Gila River south to the Gulf of California and the Magdalena, Concepción, and Altar river valleys (Broyles et al. 1997) (Figure 42). McGuire (1982d) has extended the western boundary of the Papaguería to the Colorado River. The western portion of the Papaguería is located south of the lower Gila River and east of the lower Colorado River. The Gulf of California forms its southern boundary, and an imaginary line from Gila Bend south through Ajo and Sonoyta, Mexico, to the Gulf of California is the approximate eastern boundary. The eastern portion of the Papaguería extends eastward to the Santa Cruz River and includes the Baboquivari Mountains; Three Points is the dividing line with the Tucson Basin. As used in this volume, the boundary between the eastern and western portion of the Papaguería lies south of the Gila River along the western edge of

the Sand Tank Mountains and extends south along the western edge of the Sauceda, Batamote, Ajo, and Sierra la Espuma Mountains to Bahía San Jorge, south of Puerto Peñasco, Sonora, Mexico.

The western portion of the Papaguería lies within two subprovinces of the Basin and Range physiographic province: the Salton Trough and the Sonoran Desert. The region consists of a series of rock-faulted mountain ranges divided by extensive drop-faulted basins more or less aligned in a northwest-to-southeast orientation (Ahlstrom 2000a; Fenneman 1931). The geologic relationships exposed in these mountains and their valleys provide evidence on the origin of the Basin and Range. Proterozoic (1.5–2 billion years old) and Cretaceous to Tertiary volcanic rocks form the bedrock (Keith 1971). Basaltic volcanism generally began about 23 million years ago but was more intense around 10 million years ago. Andesitic lavas, typically associated with subduction zone volcanoes, stopped in the Basin and Range by about 12 million years ago.

The evidence suggests that southwestern Arizona began to evolve into its modern landscape about 15 million years ago. Light-colored Late Cretaceous granite bedrock underlies the basaltic lava, which intrudes somewhat on Proterozoic crystalline rocks. Physical and, to a lesser degree, chemical weathering caused the granites, as in the Gunnery Range Batholith, to provide the main minerals that accumulate in the valleys, predominantly quartz, feldspars, and mica (Kresan 1997:591–596).

Three main elements characterize the western portion of the Papaguería landforms: mountain ranges, *bajadas*, and valleys (see Chapter 7). The mountain slopes of the western portion of the Papaguería tend to be steep and emerge abruptly from the valley floor. The valleys are filled with alluvium derived from the surrounding mountains, which can be more than a kilometer thick (e.g., 1.5 km thick at Growler Valley [Oppenheimer and Sumner 1980]). The elevation of the valley floors varies from 60 m above mean sea level (AMSL) west of the Growler Mountains to 350 m east of the same mountain range, exceeding 600 m eastward in the valley between the Sauceda Mountains and the Sand Tank Mountains (Ahlstrom 2000a; McClellan and Vogler 1977:11).
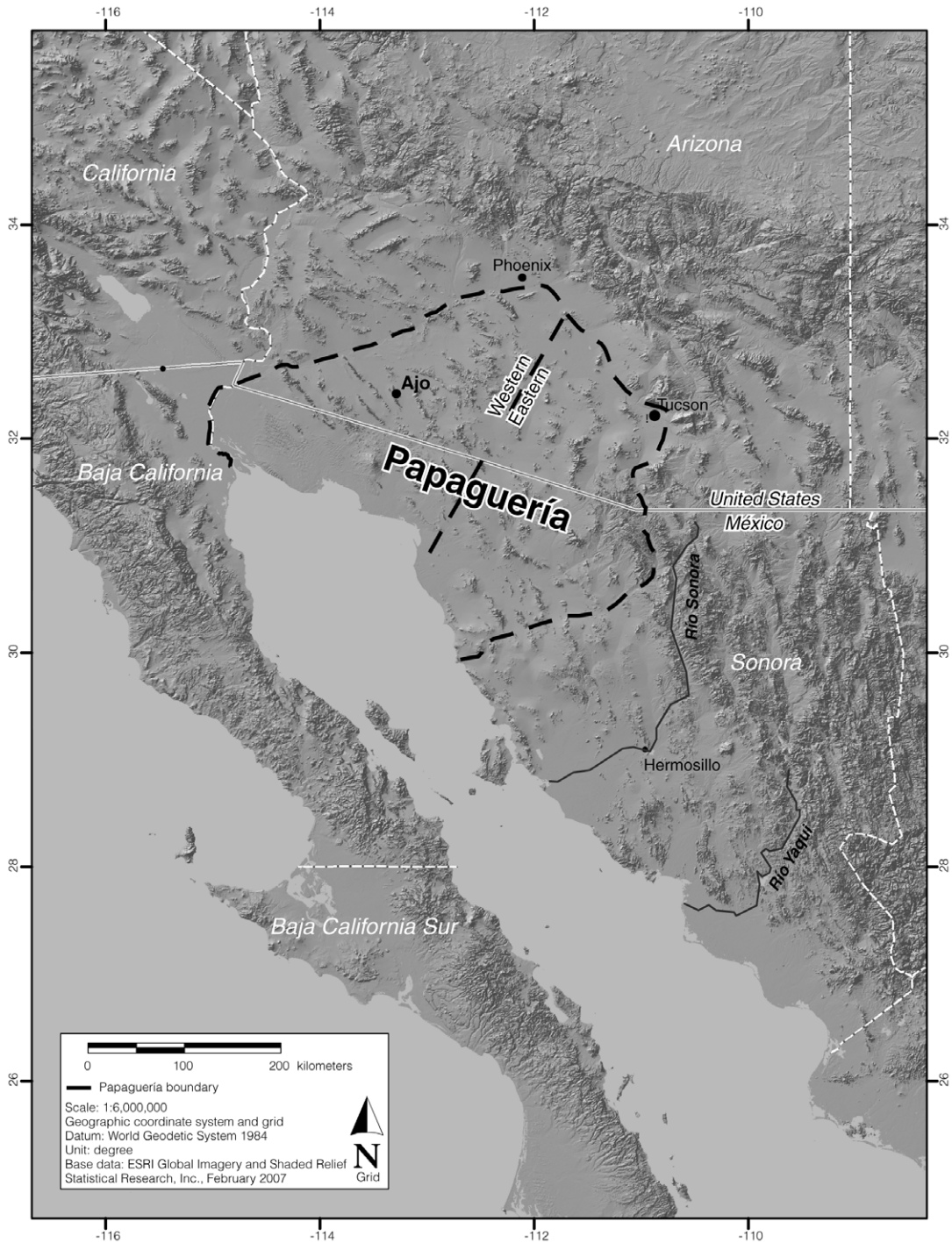
Figure 42. Location map showing the Western Papaguería boundaries, southwestern Arizona.

Coarse, poorly sorted gravels and sands transported by ephemeral streams form alluvial fans along the flanks of the mountains. These fans overlap, forming *bajadas* around the base of the mountains that extend for several kilometers (more than 20 km from the originating mountains). The ephemeral streams bisect the valleys, accumulating fine sediments (silts and clays) at their lower parts (Bryan 1925:65). Major washes generally flow down the axis of the valleys about midway between the adjacent ranges. Aeolian deposits are common on lower *bajadas* on the eastern sides of valleys (see Chapter 7).

Quaternary alluvium and aeolian deposits fill the basin floors. The oldest alluvium, deposited about 700,000 years ago, is middle Pleistocene in age, whereas the younger alluvium and aeolian deposits are mostly from the Holocene (Hill and Bruder 2000). The two main Pleistocene pediment/strath-terrace (an eroded surface produced when a broad river valley has been elevated and dissected) surfaces, lower and middle Pleistocene, are present in the Sonoran Desert, with the latter being the most extensive. In many intermontane basins, it covers nearly all the *bajadas* between the mountains and the lowlands along the axial stream (Morrison 1985:139).

Aeolian sand is common in the lower Sonoran Desert. It covers most of the Yuma Desert and large areas in the Lechuguilla Desert, Tule Desert, Pinta Sands, Mohawk Valley, Growler Valley, and San Cristobal Valley. These sands also extend outside the western portion of the Papaguería to the Great Plain, Vamori Plain, and Cactus Plain (southeast of Parker) (Morrison 1985:140). A unique characteristic of southwestern Arizona is the occurrence of desert pavement and desert varnish. Tightly packed pebbles and cobbles cover large expanses throughout the region, forming "paved" surfaces. Frequently, the desert pavement presents some chemical coating known as desert varnish. Red-brown to black, desert varnish forms on the rock surface exposed to the air in arid lands.

The Gran Desierto is an aeolian dune field that forms a sand sea covering 5,698 km^2 surrounding the Sierra del Rosario. It is the largest active dune field in North America, consisting of a "discrete area of large dunes [that] are separated by an extensive sand sheet" (Kresan 1997:578). The highest dune reaches nearly 180 m above the surrounding sand sheet. The source of the sand is the delta of the Colorado River.

Soils

Hyperthermic arid soils characterize the western portion of the Papaguería. These are dominated by two soils: Coolidge-Denure-Rillito (Growler-Mohall-Tucson complex, Guvo-Rock outcrop complex, and Cheroni-Coolidge-Hyder complex) and Gunsight-Momoli-Chuckawalla (Soil Survey Staff 2007). Gunsight-Momoli-Chuckawalla soils include deep and shallow well-drained loams and gravelly loams with moderate permeability. Coolidge-Denure-Rillito soils consist of deep, medium- and moderately coarse-textured, nearly level to gently sloping loams on low alluvial surfaces and valley plains. The Guvo-Rock outcrop complex includes shallow, gravelly and cobbly, moderately coarse- and coarse-textured, nearly level to moderately sloping to very steep soils and rock outcrops on hills and mountains. In contrast, Growler-Mohall-Tucson complex soils are deep, moderately coarse and gravelly, moderately fine-textured, nearly level and gently sloping soils on low fan surfaces and valley plains. Neither soil association is considered well suited to agricultural use today, but cultivation is possible in these soils with careful management and frequent irrigation (Hill and Bruder 2000).

Climate

The western portion of the Papaguería has a warm desert climatic regime characterized by high temperatures and low precipitation, identified as a hot climate within Koppen's classification system. McGuire (1982d) described this area as "one of the most xeric regions in the world that nonetheless allows some highly localized situations that mitigate the seemingly inhospitable nature of the region." Temperatures in the region show a wide range. For example, mild to cool temperatures of 4–21°C prevail in winter, with rare freezing temperatures in the lowlands, which typically do not last more than 24 hours (Hill and Bruder 2000; Sellers and Hill 1974). By contrast, high temperatures are the rule during the summer, with average daily highs of 32°C but reaching record highs between 40° and 50°C. As a result, a

long growing season of more than 260 days is possible in the area.

Two rainy seasons, winter and summer, contribute to an extremely low annual precipitation rate of less than 15 cm. Summer precipitation is slightly greater than winter precipitation (45–60 percent). Summer thunderstorms, known locally as "monsoons," are highly localized and violent, whereas winter storms often consist of several days of light showers (McGuire 1982d). The former are the result of convective currents that introduce strongly heated, moist air from the southeast and the Gulf of Mexico. The Pacific air mass also contributes extensive summer precipitation as it moves northward along the coast of Mexico (Hill and Bruder 2000). By contrast, the polar jet stream and the Pacific Ocean introduce winter storms, producing widespread cloudiness and light precipitation (Hill and Bruder 2000).

Hydrology

The location of reliable water sources is vital to human settlement. The Colorado and Gila Rivers are the only permanent streams of the western portion of the Papaguería, and these flow on the northern and western borders. The two rivers carry their flow, derived from rainfall and snowmelt, from the highlands in Colorado, Utah, Wyoming, Arizona, and New Mexico (Castetter and Bell 1951; Whittlesey et al. 1994). The Gila River is the major drainage of the region, draining an area of 187,000 km² that extends more than 800 km from its source in New Mexico to its confluence with the Colorado River in the southwestern corner of Arizona (Ross 1923:62). Prior to damming, the Gila River was mostly a permanent flow characterized by seasonal variations, with high peaks, including flooding, during the winter, summer rainy seasons, and low peaks late in the fall (Ross 1923:66). In dry years, the flow was intermittent (Font 1913; Whittlesey et al. 1994). The Gila's hydraulics are very different from the Colorado's—no significant tributaries enter the Gila in southwestern Arizona, and, in this region, the evaporation rate exceeds precipitation. Thus, the river decreases in volume along the lower 150–350 km (Ross 1923:62).

Ephemeral catchments that contain water only after rainfall or flooding constitute the only other water sources in the western portion of the Papaguería. These include washes, *tinajas* (rock tanks), sand tanks, *charcos* (mud holes), playas, and springs or seeps (Broyles 1996; Bryan 1925). Washes flow only after a major rain. Large washes often maintain surface flow in spots for some time. For example, the Sonoyta River has surface flow at Sonoita and at El Carrizal but is not considered to be a reliable source of water.

Formed by the weathering action of water on the granitic bedrock, *tinajas* are the most common catchments in the mountain ranges. Some are large tanks and trap sufficient rain and surface runoff to hold water for an entire year (Broyles 1996; Bryan 1925), but most *tinajas* are small and hold water for a matter of days. Some of the best-known *tinajas* occur along the trail known as El Camino del Diablo, or the Devil's Highway (Kresan 1997:595) (see Chapter 21). These include the Tinajas de los Papagos, Tinajas Altas, Tinaja Emilia, Tinaja Tule, and Tinaja de Chivos.

If a *tinaja* is filled with sand, it is called a sand tank. Natural or artificial *charcos* are found in fairly impermeable soils along wash bottoms or man-made troughs (Hill and Bruder 2000). Closed basins may form ephemeral lakes (playas) capable of holding water for extended periods in wet years. Playa lakes commonly form evaporites (salt) as the result of desiccation. Most playa lakes in the western portion of the Papaguería are found in four places: the central part of the area between the Mohawk Mountains and the Mohawk Dunes, east of the Aguila Mountains, north of Crater Range, and east and south (along the international border) of the Sierra Pinta Mountains (Ahlstrom 2000a). Las Playas (Sierra Pinta Mountains), Laguna Prieta (between the Tinajas Altas Mountains and the Colorado River), and Lago Seco (north of Crater Range) in the western portion of the Papaguería are potential sites for studying the history of a playa lake in the region (see Figure 42).

Springs and seeps (the latter having flows of less than 5 gallons per minute) are not common in the region's mountain ranges, although their abundance may be underestimated because of possible conversion into wells (Bryan 1925:163–164, 175; Rankin 1995a:15, Table 1.2). Springs in southwestern Arizona are of two types: fracture springs and fissure springs (Bryan 1925:161–167). Fracture springs depend on water

derived from rainfall stored in fractures of certain rock types (Bryan 1925). Dripping Springs in the Puerto Blanco Mountains of Organ Pipe Cactus National Monument (OPCNM) is a fracture spring (Bryan 1925:161–166). Fissure springs penetrate deep into the earth's crust, allowing groundwater to rise to the surface. Bryan (1925:161–166) classified Quitobaquito Springs in OPCNM as a fissure spring.

In addition to natural water sources, there is evidence of both prehistoric and historical-period, man-made wells with earthen-walled reservoirs (Ahlstrom 2000a; Bayman 1993, 1996a; Bayman and Fish 1992; Bayman et al. 1997; Rankin 1995a). These features may have been essential for the survival of humans inhabiting areas away from permanent water sources (e.g., Bayman et al. 2004) (see Chapter 8). These well/reservoirs have been recorded at Kuakatch Village (AZ Z:13:1 [ASM]) in OPCNM, Lost City in the Cabeza Prieta National Wildlife Refuge (CPNWR), and Verbena Village (AZ Y:8:11 [ASM]) on the Barry M. Goldwater Range (BMGR) East.

The Biota

Biodiversity in the western portion of the Papaguería is conditioned by climate, hydrology, topography, and substrate. Shreve and Wiggins (1964) and Brown and Lowe (1980a) proposed two classifications for describing the biota of the western portion of the Papaguería. Shreve and Wiggins's classification established seven subdivisions of the Sonoran Desert, three of which overlap in the region: the Lower Colorado River Valley, the Arizona Upland, and the Central Gulf Coast, extending north to south through the eastern end of the western portion of the Papaguería. Brown and Lowe later presented a hierarchical system describing biotic communities (biomes) "[as] natural formations, characterized by a distinctive vegetation physiognomy. They are plant and animal community responses to integrated climatic factors, more or less regional in scope" (Brown 1982:9). Under this scheme, the biotic communities of the western portion of the Papaguería are grouped based on the distinctive vegetation distinguishing the Lower Colorado River Valley subdivision from the Arizona Upland subdivision (Ahlstrom 2000a). Of the 34 biomes, 15 correspond to the Arizona Upland, and the other 19 belong to the Lower Colorado River Valley

(the driest subdivision). In addition, Ahlstrom (2000a) divided the 19 Lower Colorado River Valley biomes into two major series (Creosotebush–White Bursage and Saltbush) and two minor series (Creosotebush–Big Galleta and Mixed Scrub).

The Creosotebush–White Bursage series is the most widespread plant community of the Lower Colorado River Valley subdivision and covers a large part of the western portion of the Papaguería (Ahlstrom 2000a; Hill and Bruder 2000; Turner and Brown 1982). Dominant species of this community are creosotebush (*Larrea tridentata*) and white bursage (*Ambrosia dumosa*), followed by mesquite (*Prosopis* sp.), big galleta grass (*Hilaria* [*Pleuraphis*] *rigida*), ocotillo (*Fouquieria splendens*), and triangle (triangle-leaf) bursage (*A. deltoidea*). Other species of this series include western honey mesquite (*Prosopis glandulosa* var. *torreyana*), blue palo verde (*Parkinsonia* [*Cercidium*] *florida*), littleleaf (foothill) palo verde (*P. microphyllum*), and ironwood (*Olneya tesota*). This plant community commonly decreases in importance upslope on the *bajadas*, where the Saltbush series is more frequent, particularly where the soil is finer and more alkaline and has greater water-retention capacity than that of the Creosotebush–White Bursage series (Ahlstrom 2000a). Dominant species include cattle saltbush (*Atriplex polycarpa*), creosotebush, and triangle bursage.

Sandy plains and dunes are characterized by the minor Creosotebush–Big Galleta series. Creosotebush and big galleta grass dominate the group (Turner and Brown 1982). The latter serves to stabilize the dunes. The series can be found in several areas of the western portion of the Papaguería, such as the Mohawk and Yuma Dunes and the Pinta Sands. Plants in the minor Creosotebush–Big Galleta series favor upper *bajada* and pediment settings where fine-grained aeolian sediments accumulate (Ahlstrom 2000a).

The Mixed Scrub series is found along the washes and drainages within the Lower Colorado River Valley. It is more complex than the Creosotebush–White Bursage series, as it includes desert lavender (*Hyptis emoryi*) and jojoba (*Simmondsia chinensis*).

In contrast to other parts of the Lower Colorado River Valley subdivision, the Pinacate area contains scarce vegetation dominated by endemic species. Felger et al. (1992) identified two dozen plant species

that are only known from Pinacate Peak at 1,290 m (4,236 feet). Some are not known to grow in any other location within Mexico. Two grass species, *Bothriochloa* sp. and *Stipa* sp., have been recovered from pack-rat (wood rat, *Neotoma* sp.) middens (Van Devender 1990) and appear to be relics of a more widespread Pleistocene distribution of plants. Sand-adapted plants include Wiggins's croton (*Croton wigginsii*), flatseed spurge (*Chamaesyce* [*Euphorbia*] *platysperma*), sandfood (*Pholisma sonorae*), and Colorado Desert buckwheat (*Eriogonum deserticola*).

The fauna commonly associated with these plant communities include three large mammals: coyote (*Canis latrans*); desert bighorn sheep (*Ovis canadensis nelsoni*), which prefer the mountain ranges; and Sonoran pronghorn (*Antilocapra americana sonoriensis*), which live in the basins. Although mule deer (*Odocoileus hemionus*) live in the Lower Colorado River Valley subdivision, they are uncommon in the western portion of the Papaguería. Small mammals include desert cottontail (*Sylvilagus audubonii*), black-tailed jackrabbit (*Lepus californicus*), and a variety of rodents. Most mammals of the Lower Colorado River Valley subdivision avoid the high diurnal temperatures either by being active at night or by estivating (e.g., the round-tailed ground squirrel [*Spermophilus tereticaudus*]) (Turner and Brown 1982:200). Reptiles and amphibians of this biotic zone include rattlesnakes (*Crotalus*), gophersnakes (*Pituophis*), lizards, and geckos (Coss and Jickling 1986). Birds in the Lower Colorado River Valley subdivision are less diverse than in the Arizona Upland subdivision.

The Arizona Upland subdivision is characterized by the palo verde–cacti–mixed-scrub community and is restricted primarily to mountain ranges and upper *bajadas* throughout the region. Littleleaf palo verde and saguaro (*Carnegiea gigantea*) dominate the series; ironwood is a secondary component of the assemblage (Turner and Brown 1982). Other species present are creosotebush, white brittlebush (*Encelia farinosa*), limberbush (*Jatropha* sp.), white bursage, and ocotillo (Ahlstrom 2000a). An important component of the Arizona Upland subdivision in the south-to-southwest-facing slopes of mountain ranges in OPCNM is the organ pipe cactus (*Stenocereus* [*Cereus*] *thurberi*). Desert agave (*Agave deserti* ssp. *simplex*) is found in a few locations, mostly constrained to elevations above 200 m within the western portion of the Papaguería (Turner et al. 1995:50–54). Saguaro, organ pipe cactus, and desert agave are important to Native Americans today and were certainly valuable to their ancestors (Felger 2007).

The ecotone between the Arizona Upland subdivision and the Creosotebush–White Bursage series is a common feature along the margins of the many valleys of the region. In areas where the gently sloping valley floor makes contact with the base of the adjacent *bajada*, triangle bursage is commonly found growing along minor watercourses, where moisture conditions are more favorable. As elevation increases, the ecologically complementary white bursage wanes, and triangle bursage is found on all aspects of the terrain. Littleleaf palo verde, ironwood, and saguaro become increasingly prominent and are largely responsible for the arborescent physiognomy of the vegetation. Creosotebush is still present but is mostly relegated to an understory role. Many additional species are encountered that contribute to the diverse and complex nature of the community (Turner and Brown 1982:201–202).

The Arizona Upland subdivision has a more diverse fauna than the Lower Colorado River Valley subdivision. Large mammals in the region include coyote, mule deer, white-tailed deer (*Odocoileus virginianus*), desert bighorn sheep, and javelina (collared peccary, *Pecari tajacu*). The small mammals are represented by desert cottontail, black-tailed jackrabbit, and many species of rodents, including pack rats (Hoffmeister 1986; Turner and Brown 1982). Birds, reptiles, and amphibians are diverse in the Arizona Upland subdivision (Turner and Brown 1982).

The Central Gulf Coast subdivision is characterized by two disjunct areas of coastal plains on either side of the Gulf of California. The area's extreme aridity causes it to be increasingly barren of small shrubs as one approaches the gulf. One finds trees that are leafless most of the year and the addition of other plant species—tree ocotillo (*Fouquieria diguetii* and *F. macdougalii*), elephant tree (*Bursera* sp.), and limberbush—that require a frost-free environment. Although shrubs are largely absent, pure stands of creosotebush are found. For the Hia C-ed O'odham,

sandfood, a parasitic tuber that grows in the sand dunes, in addition to elephant tree and ocotillo, was of great importance as a food source (Felger 2007:166). Limberbush was used medicinally and also to make baskets (Felger 2007:160). Important animals included various lizards found in the dunes along the coast, Sonoran pronghorn, sea lions (*Zalophus*) and turtles found along the coast, and fish.

MODERN AND PAST EDIBLE AND USABLE RESOURCES

The Sonoran Desert is home to more than 200 species (Hodgson 1982) of edible and medicinal plants as well as plant material for basketry, tools, shelter, and fuel. Castetter and Underhill (1935) listed more than 30 wild plants that were eaten by the Tohono O'odham of southwestern Arizona. Comprehensive studies of O'odham use of plants are presented by Castetter and Bell (1937, 1942), Castetter et al. (1938), Castetter and Underhill (1935), Doelle (1976a, 1980), Good-year and Dittert (1973), Nabhan et al. (1989), and Felger et al. (1992). These reports provide detailed information on critical resources, productivity of various environmental zones, and various uses of the resources.

Seasonal mobility was encouraged by the characteristics of the critical resources, which include their spatial distribution, annual yield, and seasonal availability. In general, the greatest abundance and diversity of edible and material plant resources is on the *bajadas*. Based on ethnographic evidence and paleobotanical remains from archaeological contexts, the most important plant resources included three legumes (mesquite, palo verde, and ironwood), cacti (saguaro, organ pipe, and *Opuntia* spp. [cholla and prickly pear]), and agave. The edible pods and seeds of mesquite, palo verde, and ironwood typically still are and would have been available in the late summer and early fall months. The pods and seeds were pounded in bedrock and wooden mortars to obtain coarse flour (see Chapter 13). The mesquite crop was quite reliable because of the trees' long taproots, which can reach groundwater at depths of 50 m below the surface. Mesquite branches were used in house and ramada construction, for tools, and as a fuel for

roasting agave. The highest density of mesquite is found along the washes in the valleys and *bajadas.* Yearly variability in palo verde and ironwood crops was anticipated by indigenous inhabitants of the region because of the plants' dependence on rainfall for pod production (Nabhan et al. 1989).

The major food resources for O'odham people were the fruit and seeds of the columnar cacti—saguaro and organ pipe. Saguaro is found in abundance on the *bajadas* throughout the western portion of the Papaguería, whereas organ pipe cactus is confined to the southeast portion of the western portion of the Papaguería in OPCNM. The fruit and seeds of these cacti can be separated, dried, and stored for later use or can be made into jam for more immediate use. Saguaro wine is also made and is traditionally not consumed until after the first monsoon storm. The significance of the saguaro in the O'odham subsistence system is suggested by the fact that the O'odham calendar year begins with the saguaro harvest in July (Crosswhite 1981). Traditionally, a saguaro wine ceremony was held upon completion of the harvest. O'odham stories admonishing those who would harm the plant demonstrate the reverence they had for the saguaro. Saguaro ribs were used in the construction of houses and ramadas. The ribs were also used to make the *kuipaD*, the saguaro gathering pole (Figure 43).

Prickly-pear fruits and cholla flower buds constituted another important food resource for historical-period and prehistoric populations. Both cacti are abundant on the *bajada* and rocky mountain slopes. Cholla buds are available in the late spring before the May drought. The buds are roasted in shallow pits, and leaves of desert seepweed (*Suaeda suffrutescens*) are added for flavoring (Doelle 1976a; Gasser 1982a). The fruit of the prickly pear, from which dye was also obtained, is available in the early fall.

Agave also played a key role in the subsistence system of historical-period O'odham and prehistoric Hohokam and Patayan groups. The importance of this plant in the Hohokam diet was underestimated until the early 1980s. The discovery of agave macro-fossils from large roasting pits or *hornos* (ovens) at sites along the Salt-Gila Aqueduct (Miksicek 1984) provided the first evidence of the significance of this

Figure 43. Pima woman harvesting saguaro fruit with a gathering pole, 1907 (Library of Congress, Prints and Photographs Division, Edward S. Curtis Collection [LC-USZ62-111942]).

plant to the Hohokam. Since then, prehistoric agave fields (some with agave growing in them) have been identified within the *bajada* of the Tortolita Mountains near Tucson (Fish et al. 1985) and in the New River area (Rankin and Katzer 1989) north of Phoenix. The edible flower stalk is available in the late winter or early spring. In general, the agave heart, which is available year-round, was gathered when the plant flowered because of the higher quantity of sugar in the heart at that time. The heart was baked for several days in a deep roasting pit. The leaves of the agave were pounded to obtain fiber, which was used to make cordage.

ENVIRONMENTAL CHANGE AND HUMAN ADAPTATION

Paleoenvironmental scientists have documented aspects of past environmental conditions in the western deserts from evidence derived from alluvial stratigraphy, mud cores, pollen trapped in sediments, and plant materials incorporated into pack-rat middens. Depending on the lines of evidence on which they are based, models of past environmental conditions often differ. Interpreting the evidence, therefore, requires substantial expertise and a great deal of caution. McGuire (1982d), Moratto (1984), Stone (1986), and Weide (1982) have attempted to do this for western

Arizona and southeastern California. Syntheses based on more limited data sets include those by Van Devender et al. (1987), Betancourt et al. (1990), and Davis et al. (1990). These syntheses of vegetation history in the arid interior of western North America are based on data from pack-rat middens.

Little is known about the environmental history of the western portion of the Papaguería. Some studies exist for southwestern Arizona, which are used to depict the overall regional scenario from the late Pleistocene through the Holocene (Davis 1991; Ely et al. 1993; Graybill 1989; Palacios-Fest et al. 2002; Stine 1990; Waters 1980). A much smaller number of studies documents environmental change in and around the Papaguería through pollen records, pack-rat-midden analysis, and geomorphology around the area (Antevs 1948, 1955; Betancourt et al. 1990; Martin 1963; Van Devender and Spaulding 1979) (see Chapter 7).

Short- and long-term occupation in the western portion of the Papaguería dates back to at least the Paleoindian period (before 12,000 B.P. [10,000 B.C.] and perhaps earlier). Crude, flaked artifacts along the terraces and desert pavements were left by the earliest Native Americans as they searched for game and wild plants and engaged in other activities. The pluvial nature of southwestern Arizona at this time provided crucial resources like surface water, woodland vegetation, and the mammoth associated with stone tools at Quitovac and the Clovis site AZ Y:8:100 (ASM) in the BMGR (Ahlstrom, Chenault, and Wrobleski 2000).

Recent research on late Pleistocene paleoclimate supports current geomorphological, palynological, paleoecological, and archaeological records of a cooler, wetter environment in western North America, from the state of Washington in the United States to the state of Chihuahua in Mexico (Palacios-Fest et al. 2002; Van Devender and Spaulding 1979) (see Chapter 7). Under these conditions, Paleoindian people found shelter at sites like Ventana Cave in the eastern Papaguería (Haury 1950). The western portion of the Papaguería, however, might have been drier than eastern Arizona, making it less desirable for anything other than short-term use by humans.

Vegetation during the late Pleistocene–Holocene transition (14,000–8000 B.P. [12,000–6000 B.C.])

consisted of widespread singleleaf piñon–Utah juniper woodlands (*Pinus monophylla* and *Juniperus osteosperma*). Relict populations of juniper still exist in the Sand Tank and Ajo Mountains. In general, vegetation in the western portion of the Papaguería was similar to that in the Mojave Desert, with yucca (*Yucca*) and tall grasses present. Many species of animals (mammoth, giant ground sloth, camel, and horse) became extinct, particularly between 13,000 and 8000 B.P. (11,000 and 6000 B.C.) (Moratto 1984:88).

Debate on the climate history of the western portion of the Papaguería between the early and middle Holocene results from the poverty of the available record, which complicates interpretation of the archaeological record (Hill and Bruder 2000). Deep pluvial lakes of the late Pleistocene began to shrink into shallow lakes after about 11,000 B.P. (9000 B.C.), and marsh habitats expanded. The lakes began disappearing around 8000 B.P. (6000 B.C.), at the beginning of the Altithermal (Moratto 1984:93, 103). With some discrepancies, most authors concur that the onset of modern climate began around 8,000 years ago and reached its modern conditions around 4,000 years ago (Antevs 1948, 1955; Martin 1963; Van Devender 1990; Van Devender and Spaulding 1979; Whittlesey et al. 1994).

During the early Holocene, most of the western portion of the Papaguería was primarily desertscrub, with the dominant plants consisting of white bursage, creosotebush, desert agave, brittlebush, Mormon tea (*Ephedra*), and catclaw acacia (*Acacia greggii*) (Van Devender 1990:Figure 8.8). Mountain ranges like the Tinajas Altas Mountains supported the pygmy conifer woodland species of singleleaf piñon and California juniper (*Juniperus californica*).

Based on ostracode-shell chemistry at Mono Lake, California; Laguna Diablo, Baja California; and Laguna Babícora, Chihuahua, Mexico, early to middle Holocene paleotemperatures in pluvial lakes fluctuated from approximately 10 to 30°C (Figure 44). The paleotemperature reconstructions are consistent with Antevs's (1948, 1955) interpretation for western North America. A weaker correlation is observed with Martin's (1963) and Van Devender and Spaulding's (1979) pollen and pack-rat-midden records; the paleotemperature data are inconsistent with Van Devender's (1987) pack-rat-midden data.
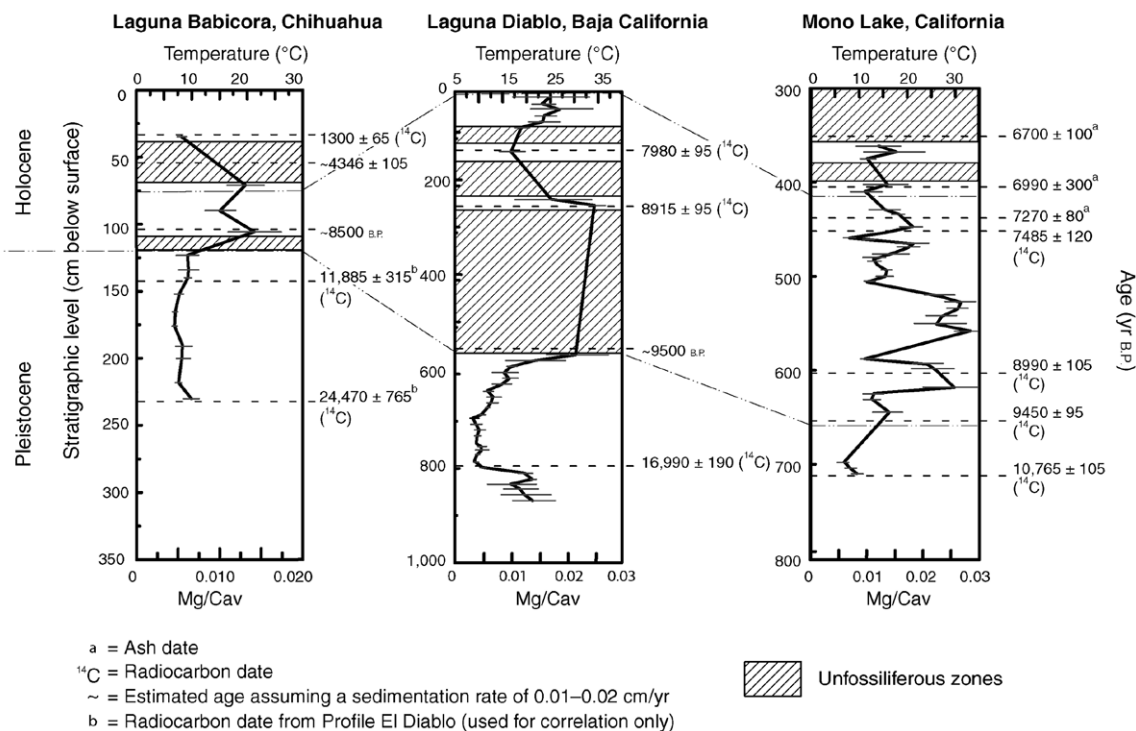
Figure 44. Paleotemperature estimates from three late Pleistocene-Holocene lakes in the vicinity of the western portion of the Papaguería: Laguna Babícora, Chihuahua, Mexico; Laguna Diablo, Northern Baja California, Mexico; and Mono Lake, California.

If similar conditions occurred in the western portion of the Papaguería during the early Holocene, humans were subjected to progressively warmer and drier conditions ca. 9,000 years B.P. (7000 B.C.), leaving springs and *tinajas* as the main, if not only, water sources for survival (Figure 45). Wetter and cooler conditions resulting from more frequent winter storms after 8,500–7,000 years B.P. (6500–5000 B.C.) introduced milder conditions that favored the settling of the area by late Early to Middle Archaic period peoples. These changes were also recorded in vegetation studies.

In the middle Holocene, catclaw acacia and blue palo verde grew on slopes; today they are restricted to washes. Littleleaf paloverde does not appear in the assemblages until the late Holocene. Van Devender (1990:148) indicated that "in the middle Holocene nearly twice as many species were growing near the rock shelters . . . as occur there today."

The climate of the middle Holocene constituted a transition between the climate of the Late Wisconsin and that of today. The middle Holocene saw the end of the winter rainfall regime and the establishment of hot summers that have persisted to the present day. Precipitation was, however, somewhat more abundant than today—summer rainfall may have been 20 percent greater in the Tinajas Altas Mountains.

According to Antevs (1948:172–175), the coolest and moistest times were between 4,500 and 2,000 years B.P. (2500 B.C.–ca. A.D. 1), whereas the last 2,000 years were drier. Antevs found the following lines of evidence to support the hypothesis that the Medithermal was "relatively cool and moist": (1) the reappearance of lakes in desert playas, (2) the reappearance of glaciers in the high mountains, (3) the redeposition in Altithermal arroyos of silts and clays, (4) the stabilization of dunes, and (5) a migration of biotic communities to lower elevations.

The early late Holocene (4000–2000 B.P.) coincides with the Late Archaic period (2200 B.C.–A.D. 200). The geological record during the past 4,000 years contains numerous episodes of arroyo cutting (Bryan 1941; Euler et al. 1979; Waters and Haynes 2001), but no researcher has attempted to correlate these episodes with major changes in the distribution or content of biotic communities. Ely (1997) synthesized the paleoflood records in the southwestern United States, including central and southern Arizona. Episodes with an increased frequency of high-magnitude floods coincide with periods of cool, wet climate conditions in the western United States, whereas warm intervals are times of dramatic decreases in the number of large floods.

How does this scenario relate to the western portion of the Papaguería? Limited information is available from the region. Van Devender's (1987, 1990) pack-rat-midden records indicate that by ca. 4,000 years B.P., the modern climatic regime was established. Of the two areas where pack-rat middens yielded information—Puerto Blanco and Tinajas Altas Mountains—only the former registered vegetation between 4,000 and 2,000 years B.P. Littleleaf palo verde, ironwood, Mexican jumpingbean (*Sebastiana* [*Sapium*] *bilocularis*), and organ pipe cactus became numerous in the middens, suggesting increasingly dry conditions. Catclaw acacia, mesquite, and blue palo verde were confined to washes, but creosotebush expanded from the south (Van Devender 1987).

During the middle late Holocene, inhabitants of the western portion of the Papaguería were becoming more adapted to the modern environment. Pack-rat middens in both the Puerto Blanco Mountains and the Tinajas Altas Mountains contained the modern botanical assemblages (Van Devender 1987, 1990).

Water availability fluctuated at this time. Waters (1980) found playa deposits at Lake Cahuilla between 2200 and 1200 B.P. (100 B.C.–A.D. 700). Stine (1990) reported a prolonged lowstand and stable period at Mono Lake, between ~1,807 years B.P. (~A.D. 200) and 1,245 years B.P. (~A.D. 850), with weak evidence

Figure 45. Rock tanks, or *tinajas*, in the Western Papaguería.

of a lake transgression around 1370 ± 45 B.P. (~A.D. 600). Similarly, Davis (1999) found that a modern assemblage had been established around Mono Lake at this time. For the same period (~2,200–1,200 years B.P.), Ely (1997) proposed an increasing frequency of floods in western North America that, however, do not stand out as particularly significant. The paleolacustrine record of Laguna Babícora, Chihuahua (Palacios-Fest et al. 2002), indicates dry and warm conditions for the period between 4346 ± 105 B.P. and 1300 ± 65 B.P. (~2100 B.C.–A.D. 200) (see Figure 44).

Long-term habitation of the western portion of the Papaguería may have been difficult at this time. Most Pioneer and early Colonial period sites (ca. A.D. 700–900) consist of small artifact scatters located near *tinajas* or springs or along the Gila River. Pollen data indicated that fresh maize (*Zea mays*) was processed at the Mobak site, a pre-Classic site with Patayan I ceramics. A study of the surrounding surface geomorphology (Phillips 2000a) indicated that the Mobak site is ideally situated for the practice of *ak chin* agriculture.

During the rest of the Colonial and Sedentary periods (A.D. 900–1150), environmental conditions frequently changed in southern Arizona. Overall, A.D. 600–1150 (1400–950 B.P.) was an active monsoon period. Summer convective storms were most intense in the A.D. 800s (~1200 B.P.). Cooler annual temperatures (Graumlich 1993; LaMarche 1974) and wet winters (Dean 1988; Graybill 1989; Rose 1994) would have enhanced effective precipitation. Farming would have been productive, although frosts may have been more common.

The end of the Sedentary period is associated with droughts and unstable climate consistent with the sharp drop in the frequency of large floods in the Southwest from A.D. 1100 to 1300 (Ely 1997). Stine (1990) also indicated the decline of Mono Lake levels after 900 years B.P. (ca. A.D. 1100), following a brief highstand. Modern flora recorded at pack-rat-midden sites indicated that after a brief appearance of velvet mesquite (*Prosopis velutina*) around A.D. 1000, modern climate prevailed (Van Devender 1990). By this time, the Hohokam had mastered irrigation agriculture in the Phoenix and Tucson Basins. In the western portion

of the Papaguería, evidence from the late Colonial and Sedentary periods indicates that people were rapidly adapting to the environment as they learned to control water by building canals, reservoirs, and wells.

Environmental instability was the norm across western North America throughout the Ceramic period. Waters (1980) has inferred multiple lateral migrations of the Colorado River to the northwest during the last 1,300 years. These river movements generated lacustral stages of Lake Cahuilla in southern California around A.D. 850, 950, and 1050 and from A.D. 1200 to 1350 and A.D. 1500 to 1600. The lakes formed focal points for prehistoric human occupation. It is possible that at least some of the western portion of the Papaguería's dry playas (e.g., Lago Seco) might have filled at similar times and supported human settlements, as suggested by the frequency of Classic period ceramics along the edges of the playas. However, this wet period was not uniform; it alternated with warm and dry intervals like those recorded elsewhere in southwestern North America in A.D. 800, 900, and 1000 (Ely 1997). Closer to the western portion of the Papaguería, Palacios-Fest (1997a) calculated water temperature and salinity of irrigation canals from the late Pioneer period to the Classic period (A.D. 700–1450) at Las Acequias in the Phoenix Basin. Ostracode-shell-chemistry paleotemperature and paleosalinity records indicate that between A.D. 600 and 1150, at least two episodes of cool and dilute water entered some Hohokam irrigation canals (Palacios-Fest 1997a). Graybill (1989) and Ely (1997) reported large floods of the Salt River around A.D. 850, 925, and possibly ca. 1100, which is consistent with shell chemistry.

The late Holocene I (1000–500 B.P.) period was marked by increasing aridity. Ely (1997) documented a sharp drop in the frequency of large floods in the southwest from 800 to 600 years B.P. (A.D. 1100–1300) corresponding to the Medieval Warm Period, first identified in European historical records approximately from A.D. 900 to 1300. Several paleoenvironmental records from the southwestern United States indicate a brief cold, wet interval about 1000 B.P. followed by warm, dry conditions (e.g., Davis 1994; Graumlich 1993; LaMarche 1974; Leavitt 1994; Petersen 1994). By this time, modern vegetation (desertscrub) was well

established in the western portion of the Papaguería (Van Devender 1987, 1990; Van Devender and Spaulding 1979).

In the western portion of the Papaguería, a number of sites, like Kuakatch, Lost City, and Verbena Village (late Sedentary through late Classic, with the strongest evidence for Classic–late Classic period occupation), provide evidence of water sources near the distal ends of *bajadas* between A.D. 1150 and 1500. For example, at Lago Seco, located north of Crater Range, Huckell (1979) discovered a Classic–late Classic period component. Evidence of "recent" lacustrine phases is vague and demands a detailed study.

In addition, Kuakatch Village in OPCNM (Rankin 1995a) included a reservoir dated between A.D. 1280 and 1425 (539 ± 38–753 ± 38 B.P.) (Bayman et al. 2004; see Chapter 8 of this volume). Biological remains indicate the reservoir held water on a long-term basis (see Chapter 8). Other sites, like Verbena Village and the Growler Bend site, contained abundant artifacts scattered on the surface, indicating likely year-round occupation. Verbena Village has a well/reservoir, and evidence suggests that Daniels Arroyo was modified into a canal. Pollen samples from possible field areas yielded maize pollen. Dry conditions led to a drop in water tables and a reduction in vegetation cover that protected the desert valleys from erosion (Tucker, Thurtle, et al. 2000).

The last 500–600 years show a substantial jump in the number of floods in the southwestern United States that is associated with a switch to glacial advances, high lake levels, and cooler, wetter conditions recorded across the region (Cole and Webb 1985; Curry 1969; Davis 1988; Ely 1997; Enzel et al. 1992; Grove 1988). Evidence from around the world indicates a cooler climate during the Little Ice Age, spanning approximately the fifteenth to mid-nineteenth centuries (Bradley and Jones 1992; Ely 1997; Grove 1988). The twentieth century began with anomalously high flood rates in the Southwest, as indicated by modern records and tree-ring reconstructions (Ely 1997). In southern Arizona, Waters and Haynes (2001) documented at least three episodes of arroyo cutting on the Santa Cruz River and the tributaries of the San Pedro Valley over the last 500 years. These events seem to correspond to the

dry-wet climatic cycles that characterized the region for the past 4,000 years.

The early part of the late historical period witnessed the end of the Little Ice Age (1600s–1850s), a wet and cool episode documented through high-magnitude floods (Ely 1997) and dendrochronology (Sheppard et al. 2002) that likely contributed to the rise of the water table in the area. The incorporation of technological strategies for mining and digging wells made the native peoples less vulnerable to environmental change.

CONCLUSION: IT REALLY IS ALL ABOUT WATER

It is evident that regional landscape, geology and soils, climate, hydrology, and the biota had major effects on human populations occupying the western portion of the Papaguería. Limited water, combined with high temperatures and low precipitation, probably represented the greatest challenge. Most human decisions, including where to live and for how long, were guided by the availability of water. People moved through the western portion of the Papaguería by "connecting the dots" of natural and man-made water holes. Travel could be swift, and it could be possible to traverse the entire region in 2–5 days (Broyles 1996:492). Castetter and Underhill (1935) reported that the salt migration to the Gulf of California was a 6-day round-trip journey from the Santa Rosa area but only a 4-day round trip from the vicinity of Menegers Dam. The abundance of campfires recorded within the BMGR is a quiet testimony to the intense traveling activity that occurred across the western portion of the Papaguería over time. Many of these camps were miles away from water sources but near sources of food, suggesting that water was carried to where it was needed, as Ezell (1954:20) and Broyles (1996:490) have noted. In addition, the archaeological record indicates the continuous use of the area by humans. Traveling across the area may have been less of a problem than attempting to settle there for any length of time, although there is evidence that some groups resided in locations at least seasonally (Ahlstrom 2000a; Altschul and Shelley 1987; Hill and Bruder 2000; Homburg et al.

1994; McGuire and Schiffer 1982; Rankin 1995a; Tucker 2000a).

Human movement across the western portion of the Papaguería did not only rely on scarce natural water sources but also on constructed earthen-banked reservoirs, or *charcos*. These facilities allowed the establishment of seasonal and, in some cases, permanent habitation sites like Verbena Village or Kuakatch Village (Bayman 1996a; Olszewski, Darrington, and Bauer 1996; Rankin 1995a). Bayman (1996a), Bayman et al. (2004), and Palacios-Fest et al. (see Chapter 8 of this volume) have argued that some of the reservoirs in the western portion of the Papaguería held water on a year-round basis. The existence of these features makes the long-term occupation of the sites plausible. As Homburg et al. (1994) argued, the high artifact density and ratios of ceramics to lithics in several sites around or near natural or artificial water sources across the western portion of the Papaguería imply at least seasonal occupation.

Although water availability was always foremost in the minds of the residents of the western portion of the Papaguería, they were keenly aware of the distribution of the region's biotic and mineral resources. Climate change throughout the Holocene led to changes in the distribution and density of biotic resources and encouraged innovative adaptive strategies. Although we tend to view the western portion of the Papaguería through our ethnocentric lenses as one of the harshest places on Earth, "once where to look for water is known, the difficulties in making a living out there are not so great as one would expect," as Carl Lumholtz (1990:330) noted. For those who could read the desert, the western portion of the Papaguería was home, the best place on Earth. For others, it was hell.