

Upham, S., R. S. MacNeish, W. C. Galinat, and C. M. Stevenson

- 1987 Evidence concerning the Origin of Maíz de Ocho. *American Anthropologist* 89(2): 410–418.

Van Devender, T. R.

- 1990a Late Quaternary Vegetation and Climate of the Chihuahuan Desert, United States and Mexico. In *Packrat Middens: The Last 40,000 Years of Biotic Change*, edited by J. L. Betancourt, T. R. Van Devender, and P. S. Martin, pp. 104–133. University of Arizona Press, Tucson.
- 1990b Late Quaternary Vegetation and Climate of the Sonoran Desert, United States and Mexico. In *Packrat Middens: the Last 40,000 Years of Biotic Change*, edited by J. L. Betancourt, T. R. Van Devender, and P. S. Martin, pp. 134–165. University of Arizona Press, Tucson.

Waters, M. R., and A. I. Woosley

- 1990 The Geoarchaeology and Preceramic Prehistory of the Willcox Basin, Southeastern Arizona. *Journal of Field Archaeology* 17: 163–175.

Whalen, M. E.

- 1981 Origin and Evolution of Ceramics in Western Texas. *Bulletin of the Texas Archeological Society* 52: 215–229.
- 1994 Moving Out of the Archaic on the Edge of the Southwest. *American Antiquity* 59: 622–638.

Wills, W. H.

- 1988 *Early Prehistoric Agriculture in the American Southwest*. School of American Research Press, Santa Fe.

Wills, W. H., and B. B. Huckell

- 1994 Economic Implications of Changing Land-Use Patterns in the Late Archaic. In *Themes in Southwest Prehistory*, edited by George J. Gumerman, pp. 33–52. School of American Research Press, Santa Fe.

Winterhalder, B., and E. A. Smith (editors)

- 1992 *Evolutionary Ecology and Human Behavior*. Aldine de Gruyter, New York.

Yellen, John

- 1977 Long-term Hunter-Gatherer Adaptation to Desert Environments: A Biogeographical Perspective. *World Archaeology* 8(3): 262–274.

The Transition to Farming on the Río Casas Grandes and in the Southern Jornada Mogollon Region

ROBERT J. HARD AND JOHN R. RONEY

Poorly understood variability characterizes the rate at which hunting and gathering economies evolve into farming ones at global and regional scales. In Southwestern North America farming economies were typically established with the formation of early pithouse settlements in the Hohokam, Anasazi, and Mogollon regions between ca. AD 200 and 700. Recent investigations have shown that significant use of maize was underway by ca. 1200 BC in southern Arizona (Huckell 1995; Huckell et al. 1995; Mabry 1998, 2002, 2003; Mabry et al. 1997). The extremes of this variability are particularly evident in the vicinity of the New Mexico–Chihuahua international border. Along the Río Casas Grandes in Chihuahua, Native Americans living at the site of Cerro Juanaqueña had made significant investment in farming by 1200 BC. Yet only 30–200 km to the northeast, the people of the Jornada Mogollon region, living along the Rio Grande, did not markedly invest in farming until ca. AD 1000–1100 (Figure 6.1).

Recent advances in optimal foraging theory combined with new data from Cerro Juanaqueña may offer utility in understanding this variability. A description of the results of four years of excavation at the site provides background for the comparison between the formation of farming communities in the Jornada region versus the Río Casas Grandes region.

Cerro Juanaqueña

Cerro Juanaqueña, dating to 1250 BC, not only represents an early aggregated settlement; it also predates most other *cerros de trincheras* (literally hill with trenches or walls) by about 2,000 years. *Cerros de trincheras* are complexes of hilltop terraces, rock rings, and stone walls that typically date to after AD 1200 and are associated with the large populations of agriculturalists in the Hohokam and Trincheras culture areas of southern Arizona and northern Sonora, Mexico (e.g., Johnson 1960; McGuire et al. 1999; McGuire and McNiff


Texas Archaeology and Ethnohistory Series
Thomas R. Hester, EDITOR

THE LATE ARCHAIC across the Borderlands

From Foraging to Farming



Edited by Bradley J. Vierra

UNIVERSITY OF TEXAS PRESS  AUSTIN

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Printed in the United States of America
First edition, 2005

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University of Texas Press
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Library of Congress Cataloging-in-Publication Data

The Late Archaic across the Borderlands : from foraging to
farming /

edited by Bradley J. Vierra. — 1st ed.

p. cm. — (Texas archaeology and ethnohistory series)

Includes bibliographical references and index.

ISBN 0-292-70669-3 (cl. : alk. paper)

1. Indians of Mexico—Mexican-American Border Region—Antiquities. 2. Indians
of North America—Mexican-American Border Region—Antiquities. 3. Indians of
Mexico—Agriculture—Mexican-American Border Region. 4. Indians of North America—
Agriculture—Mexican-American Border Region. 5. Hunting and gathering societies—
Mexican-American Border Region. 6. Excavations (Archaeology)—Mexican-American Border
Region. 7. Mexican-American Border Region—Antiquities. I. Vierra, Bradley J. II. Series.

F1219.L1.M63138 2005

972'.101

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To
Lewis R. Binford,
Lawrence G. Straus,
and
Cynthia Irwin-Williams
for teaching me about
hunter-gatherer archaeology

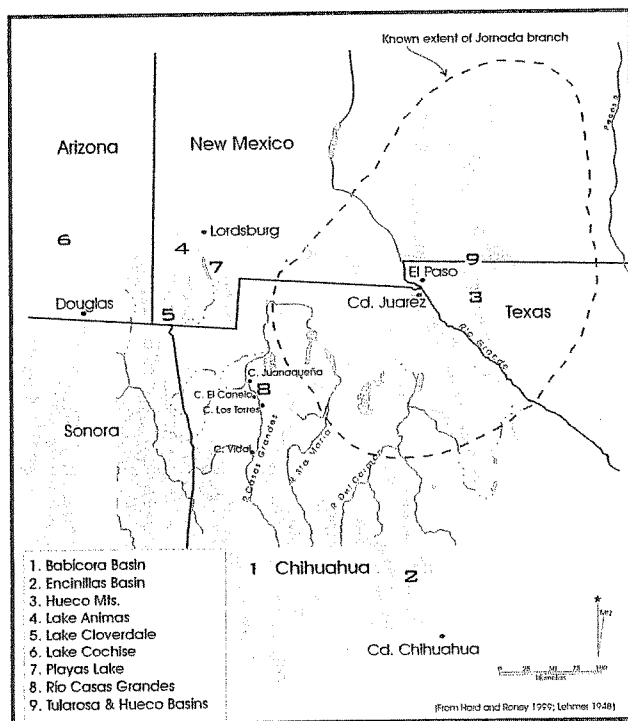


Figure 6.1. Jornada Branch of the Mogollon region (indicated by the dashed line), including both northern and southern areas (Lehmer 1948). Most of the Jornada data used in this paper are from the vicinity of El Paso. Cerro Juanaqueña and three other Late Archaic period *cerros de trincheras* sites are located along the Río Casas Grandes. The numbers 1 to 9 represent locales with paleoecological information.

1990; McGuire and Villalpando 1993; O'Donovan 2002; Sauer and Brand 1931; Stacy 1974; Wilcox 1979; Zavala 1998). Cerro Juanaqueña is a large, aggregated, intensively occupied *cerro de trincheras* with 550 terraces and 99 rock rings. Two-thirds of the features are on a 6-ha area of the summit and upper slopes, and the balance are on a 4-ha area on the western side of the hill just above the floodplain (Figure 6.2).

Native Americans constructed the terraces by first piling the local basalt cobbles to form berms that bow out in the center and pinch in at the ends against 5–40% slopes (Figure 6.3). Occasionally rocks were stacked. The pocket between the apex of the berm wall and the natural slope behind was then filled

in with smaller rocks (Figure 6.4). Finally sediment capped the construction to form a level to slightly sloping surface. The mean area of these terraces is 52 m² (Hard et al. 1999). The constructed terraces cover a total area of 8 ha and include almost 8 linear km of terrace wall. In order to evaluate construction effort we built a terrace that was similar to the ancient ones (Hard et al. 1999). Volumetric estimates of all features suggest that 40,000 tons of rock and sediment were moved during their construction. This effort would have required thirty person-years of labor, an effort equivalent to the construction of a 550-room pueblo (Hard et al. 1999).

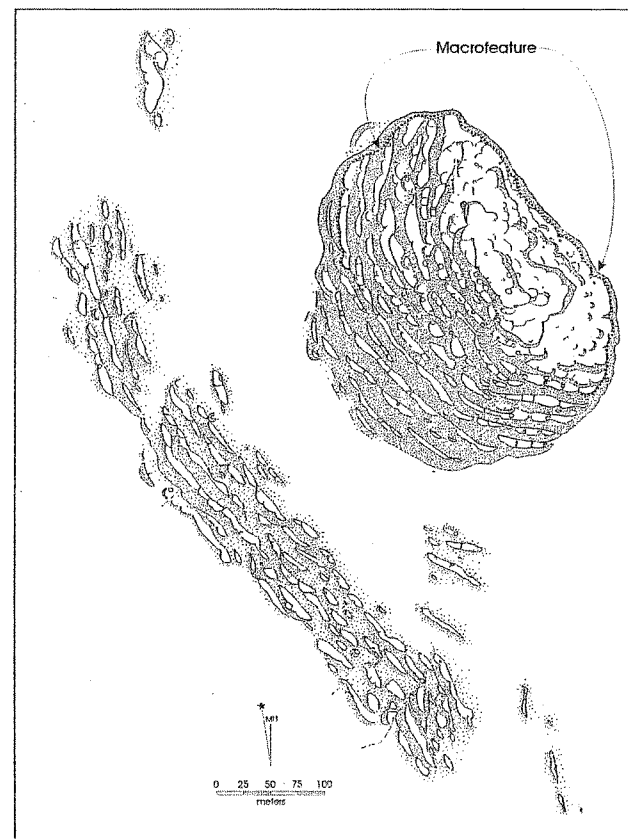


Figure 6.2. Cerro Juanaqueña plan view. The macrofeature is a continuous terrace/berm wall that forms the site perimeter on the north, east, and south sides.

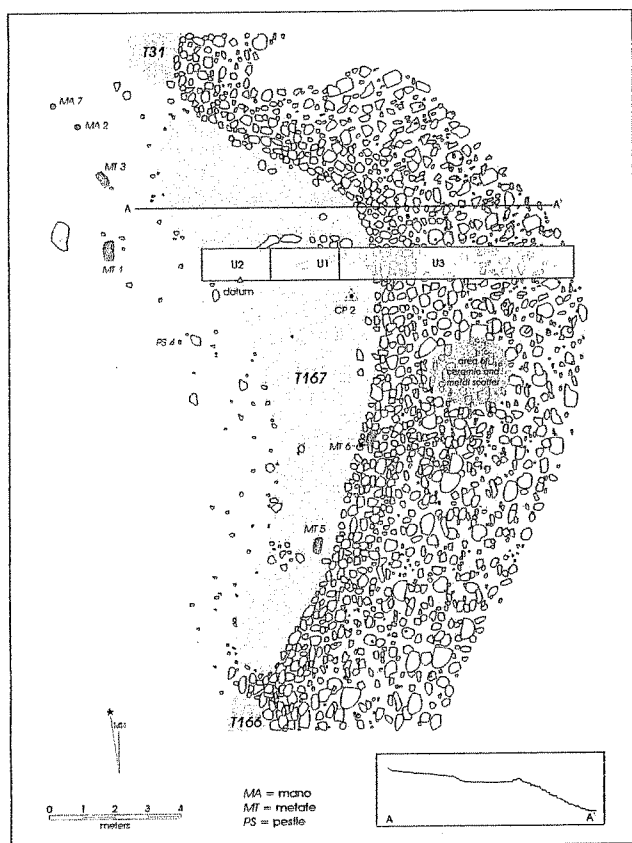


Figure 6.3. Plan view of Terrace 167

The site layout shows elements of planning (Hard et al. 1999). About twenty-two adjoining terraces and two walls form a 400-m continuous berm wall or macrofeature (Figure 6.2) that bounds the northern, eastern, and southern sides of the site. About 40% of the terraces form articulated linear groups of about two to five terraces each built on a single contour. Individual terraces within the groups are demarcated by constricted points along the berm walls or by small cross walls lying perpendicular to the berm wall. Typically, multiple terraces or terrace groups are built along the same contour, so one can walk significant distances around the hill with little change in elevation. There is roughly even spacing among bands of terraces up and down slope. No doubt some of these organizational aspects are the result of using the natural topog-

raphy of the hill to best advantage, but the overall pattern and symmetry to the site indicates that internal site planning was under the direction of a recognized leader (Hard et al. 1999).

The terraces were primarily constructed to serve as living surfaces and house platforms. Household debris, including numerous basin and slab metates, manos, burned and unburned bone, lithic manufacturing debris, projectile points, cores, hammerstones, charred and uncharred bone, ashy sediment, and trash midden deposits, is common on the surface and within the excavated terrace construction fill.

While archaeologists have argued that many terrace features on *trincheras* sites in southwestern and northwestern Mexico were constructed as agricultural features, the Cerro Juanaqueña terraces appear to have been too energetically costly to be constructed for this purpose. The approximately 2.5 ha of potential planting area is too small and costly to construct for effective agriculture. If all the terraces were planted in maize the harvest would only support about four adults a year (Hard et al. 1999). The high labor cost per hectare of potential planting area exceeds that of other agricultural terracing systems and would even exceed the costs of constructing Maya raised fields (Hard et al. 1999). In addition, the thin soil and absence of water control features on the terraces

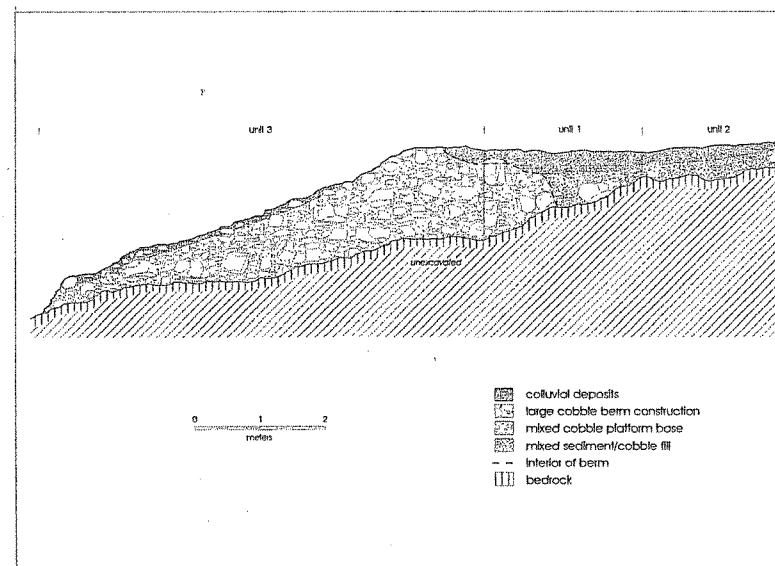


Figure 6.4. Profile of Terrace 167

suggest that farming would have been far more successful in the floodplain of the Río Casas Grandes immediately below the site.

Associated with the terraces are rock rings, which tend to cluster on the hilltop and upper one-third of the slopes. This distribution tends to correlate with the greatest surface concentrations of ground stone. The diameters of the 99 rings are normally distributed, and the mean is 2.63 m (std. dev. = 0.86 m). Most rings were constructed on terrace surfaces or on slight platforms built on the terraces. Some are semicircles with openings in various directions, but most are complete circles or ovals. Excavations revealed little in the way of floor features or in situ assemblages, perhaps in part due to the poorly preserved living floors. One ring (R239) contained a small, shallow, basin-shaped hearth with small burned rocks. Another ring contained a basin metate on the floor. At least some of these rock rings served as foundations for small circular structures.

We excavated two adjacent large storage pits that were constructed into one of the lower terraces. Both were roughly cylindrical, about 90 cm in diameter and 1.8 m–2 m deep. The first was clearly rock-lined. Both contained substantial amounts of charred and uncharred animal bone as well as more charred plant remains than found in other site contexts. An AMS date on maize from one of the pits identified them as contemporaneous with the primary site occupation. These pits offer the first direct evidence of food storage at Cerro Juanaqueña.

The terrace features are associated with a dense and varied assemblage of artifacts, including projectile points, basin metates, slab metates, manos, chipped stone drills or awls, small cruciform-shaped objects, cores, hammerstones, tubular stone pipes, stone and bone pendants, bone awls, and large quantities of debitage (see Vierra, this volume, for an analysis). We recovered over 300 dart points and another 200 bifaces and preforms most likely related to projectile point manufacture. Point styles from both surface and excavated contexts are characteristic of the Late Archaic period. They include forms similar to San Pedro, Hatch, Hueco, En Medio, Shumla, and Diagonal Notched types (Hard and Roney 1998a:1662; MacNeish 1993; Martin et al. 1952; Turner and Hester 1995; Turpin 1991). All of these types were used between 1500 BC and AD 1000 but were most common during the earlier portion of this period (MacNeish 1993; Roth and Huckell 1992; Turner and Hester 1995; Turpin 1991). The other artifacts which corroborate a Late Archaic age include over 500 whole and fragmentary slab and basin metates, small oval to round manos, tubular stone pipes, shallow stone mortars or bowls, small mushroom-shaped pestles, and stone cruciforms (Hard and Roney 1998a:1662, 1999, 2004; Roney and Hard 2002).

The large numbers of manos and metates found on the surface and in excavations offer insight into processing activities at Cerro Juanaqueña. Based on a sample of 80 whole manos from surface contexts, 80% were manufactured

Southwest Rank Order Maize Ubiquity & Mano Area

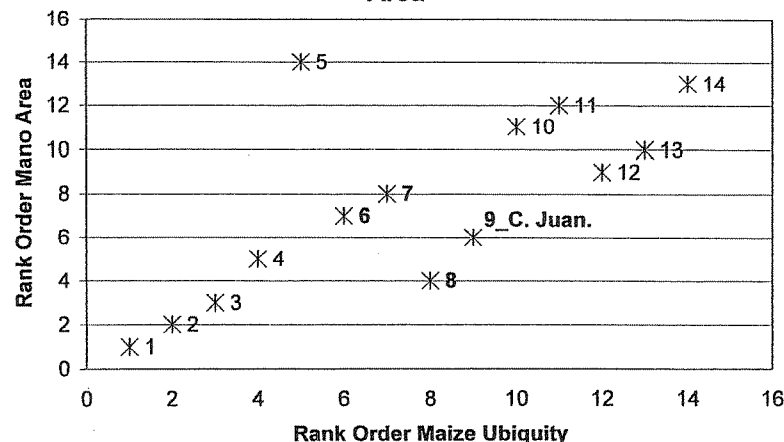


Figure 6.5. Scattergram showing rank order of mano area and maize ubiquity from Cerro Juanaqueña and other Southwestern components. 1 = Southern Jornada Late Archaic; 2 = Cedar Mesa Archaic; 3 = Southern Jornada Mesilla phase (early pithouse); 4 = Antelope Creek phase, Texas; 5 = Black Mesa Late Pueblo; 6 = Southern Jornada Doña Ana phase (late pithouse); 7 = Black Mesa Early Pueblo; 8 = Black Mesa BM II; 9 = Cerro Juanaqueña; 10 = Southern Jornada El Paso phase (pueblo); 11 = Mesa Verde BMIII; 12 = Northern Jornada Lincoln phase (pueblo); 13 = Cedar Mesa BMII; 14 = Mesa Verde PII–PIII (see Hard et al. 1996). Other mixed economies similar to Cerro Juanaqueña are in boldface.

from local basalt, with the balance made from rhyolite and unknown materials. The manos tend to be circular to oval in plan and flat to spheroid in cross section. Most of these shapes were likely used with the heavily worn, large basin metates. The mean area of all manos is 115.3 cm² (std. dev. = 51.6 cm², $n = 48$), and the mean length is 11.6 cm (std. dev. = 2.7 cm, $n = 48$). These are small compared to those found in later pueblo sites, yet they are somewhat larger than typical Archaic manos.

Recent research (Hard 1990; Hard et al. 1996; Mauldin 1993; although see Adams 1999) suggests that mano size is related to agricultural dependence. Figure 6.5 is a rank-order scattergram representing maize ubiquity and mano area for fifteen Southwestern components.

Cerro Juanaqueña clusters with the Dona Aña (Late Pithouse) phase of the Jornada Mogollon, Black Mesa Basketmaker II, and Black Mesa Early Pueblo occupations. These exhibit a middle level of agricultural use, falling between

most puebloan occupations and dominantly hunter-gatherer adaptations (Hard et al. 1996).

Metates and metate fragments are more common than manos, with as many as 20 metate pieces occurring on one terrace. There are 961 mano and metate pieces on the surface of the site. The basin metates are large and heavily worn, with steeply angled sides that form almost a V-shaped basin. The mean depth of basin wear is 8.06 cm (std. dev. = 3.95 cm, $n = 44$). This degree of wear represents intensive food-grinding activity over many generations. Estimates of wear rates suggest that the sum of the wear on all of the Cerro Juanaqueña basin metates is the result of 20,000 person-years of food processing (Roney and Hard 2002).

In addition to our work on Cerro Juanaqueña we have documented twelve other *cerros de trincheras* in the Río Casas Grandes drainage and the adjacent Río Santa María drainage (Roney and Hard 2004). Three are radiocarbon-dated to the Late Archaic period and are briefly discussed below (for their locations, see Figure 6.1). The rest are undated, but other evidence suggests that most of them belong to the Late Archaic period as well (Roney and Hard 2004).

Cerro el Canelo is only about half the size of Cerro Juanaqueña, but it is comparable in terms of setting, construction, overall layout, and range of activities represented. The site is constructed on a 160-m high hill along the Río Casas Grandes. It contains about 250 terraces that form 3.9 linear km of construction and 50 rock rings. Like Cerro Juanaqueña, Cerro el Canelo contains linked terraces that form macrofeatures up to 350 m long. Two radiocarbon dates are from the main part of the site. One AMS date on ocotillo is 2990 ± 45 b.p. and places the site as exactly contemporaneous with Cerro Juanaqueña. A second AMS date of 330 ± 60 b.p. on a charred monocot fragment from the same feature is probably the result of a historic fire. In a low saddle near the base of the hill is a stone circle 70 m in diameter, defined by a rubble berm. A fragment of a large mammal bone recovered from the berm yielded a conventional radiocarbon date of 630 ± 50 b.p. Despite this result, we still suspect that the feature is contemporaneous with the other terraces at Cerro el Canelo. The mode of construction, patination on the rocks, and vegetation on the berm are identical to those on the main terrace complex. There is comparatively little evidence of Ceramic period occupation and no ceramic or other artifact associations that suggest Ceramic period use of the feature itself (Roney and Hard 2004). Basin and slab metates, small manos, chipped stone, stone bowls, and a number of Late Archaic projectile points are similar to those at Cerro Juanaqueña, although the density is somewhat lower.

Cerro los Torres is an isolated 80-m high basaltic hill located near the eastern margin of the Río Casas Grandes floodplain, almost a kilometer from the

river (Figure 6.1). A majority of the terraces on this site are arc-shaped with rubble berm construction, comparable to those at Cerro Juanaqueña and Cerro el Canelo. A 500-m long continuous rubble berm defines the western and southern edge of the site, and eight well-defined rock rings occur among the 2.3 linear km of terrace and berm walls. The range of artifacts is similar to other Late Archaic *trincheras* sites in the region. A single AMS radiocarbon date from a maize cupule of 2920 ± 55 b.p. places the site occupation as contemporaneous with Cerro Juanaqueña and Cerro el Canelo (Roney and Hard 2004).

Near Haciendas San Diego the Río Palanganas and the Río Piedras Verdes unite to form the Río Casas Grandes. Cerro Vidal is a 120-m-high hill that overlooks this confluence. Terrace construction at this site resembles that documented at other *cerros de trincheras* in northwestern Chihuahua. At Cerro Vidal, however, individual arcs are often difficult to define. Instead the terraces form macrofeatures which describe two concentric rings around the summit, a large lobe appended to these, and an outer berm/terrace which circles the entire complex. There are about 37 rock rings and 2.2 linear km of berm/terrace construction. The density and range of artifacts are similar to those at Cerro el Canelo and Cerro Los Torres. Two AMS radiocarbon dates on maize cupules from the same feature yielded dates of 2100 ± 40 b.p. and 2340 ± 55 b.p. (Figure 6.6). As discussed below, this date is similar to evidence of a late occupation on the lower terraces of Cerro Juanaqueña.

Radiocarbon Dating

Seventeen AMS radiocarbon dates on maize or other short-lived charred plant materials are presented in Figure 6.6 (for additional details, see Roney and Hard 2002: Table 2). Of the twenty-four features excavated, thirteen yielded short-lived plant material suitable for dating which minimized the "old wood" problem. All samples were taken from within cultural terrace fill or terrace walls. During feature excavation we frequently observed downward vertical movement of fill through the voids among the rocks. Botanical preservation was better at lower depths. If dates from a particular feature were anomalous, we submitted additional samples for better evaluation of the results. Figure 6.6 presents the calibrated frequency distribution for these radiocarbon ages, based on the radiocarbon calibration program OxCal (Bronk Ramsey 1999).

The 17 dates fall into three distinct clusters. The earliest is a single date, NSRL 3985, at 3310 BP from Terrace T222. This date is statistically different from 2 other dates from the same feature, as well as the other 13 dates from the site, and should be rejected (Hard and Roney 1998a; Roney and Hard 2002). The next 14 dates cluster around 3000 BP. A T' test statistical procedure (Ward and

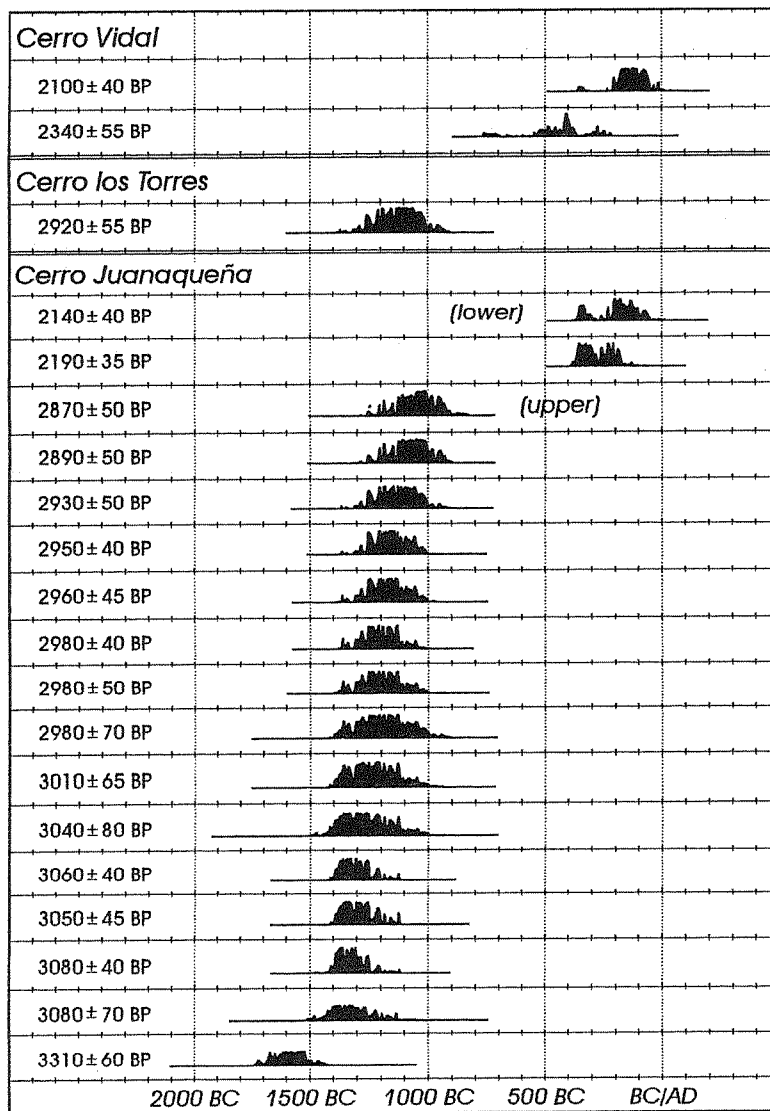


Figure 6.6. Calibrated radiocarbon dates using OxCal calibration program (Bronk Ramsey 1999). “Lower” indicates two dates from a terrace on the lower slope of Cerro Juanaqueña; “upper” refers to the remaining fifteen dates from the upper slope and top of the site.

Wilson 1978) shows that these 14 dates are compatible with a single population, implying that they are statistically contemporaneous. It is then appropriate to average the 14 dates and calibrate the results. This procedure yields a two-sigma result of BC 1270–1140, a calendrical date that approximates the principal occupation at Cerro Juanaqueña. This is contemporaneous with the dates from Cerro el Canelo and Cerro los Torres. We have also used the calibration program OxCal (Bronk Ramsey 1999) to estimate the probable span of this occupation. We found that at the two-sigma level (95.5% confidence interval) the span of the principal occupation is more than 100 years and less than 550 years, with a midrange of about 200–300 calendar years (Hard and Roney 2004; Roney and Hard 2002).

The final cluster consists of the two most recent dates listed in Figure 6.6, which are also statistically contemporaneous. They come from a single terrace in the lower terrace complex at Cerro Juanaqueña. Their two-sigma calibrated average is 360–160 BC. These two dates probably reflect a limited reoccupation of the lower portion of the site. They are contemporaneous with the occupation of Cerro Vidal (Figure 6.6).

Subsistence

Bone is well preserved in the terraces, and faunal analysis by Kari Schmidt and Jennifer Nisengard (1999, 2000) shows that 90% of the 1,794 Number of Identified Specimens (NISP) are lagomorphs; 80% of these are jackrabbits (*Lepus* sp.), with the balance being cottontail rabbits (*Sylvilagus* sp.). Artiodactyls, including deer (*Odocoileus* sp.), pronghorn antelope (*Antilocapra americana*), and a few big horn sheep (*Ovis canadensis*), account for an additional 5% of the NISP, and the other 5% consists of a variety of fish, reptiles, amphibians, birds, rodents, and carnivores. The heavy fractions of our flotation samples yielded 261 identifiable specimens. Fish and rodents dominate this assemblage, accounting for 29% and 53% respectively of the identifiable heavy fraction bone (see Hard and Roney 2004 for further discussion of fish remains).

Charred plant remains were recovered primarily from flotation samples as well as from our screens during excavation. Karen Adams found charred maize parts to be the most common plant present (Table 6.1). Maize was found in 60% of all excavated features ($n = 20$) and 40% of all analyzed light fractions ($n = 117$), suggesting that it was a dietary staple (Adams 1998, 1999a, 1999b; Hanselka 2000; Hard and Roney 1998a, 1999; Roney and Hard 2002). Chenopium was the next most frequently recovered charred taxon, including both non-domesticated chenopodium and probable domesticated amaranth (see below). Other taxa recovered include unidentified grasses, Plains lovegrass, bulrush,

Table 6.1. Charred plant remains at Cerro Juanaqueña

| Taxa | Percentage of Features |
|--|------------------------|
| | n = 20 |
| Corn (<i>Zea mays</i>) | 60 |
| Cheno-am | 45 |
| Unidentified grasses (Gramineae) | 20 |
| Bulrush (<i>Scirpus</i> sp.) | 15 |
| Chia (<i>Salvia</i> sp.) | 10 |
| Unidentified monocot (Monocotyledon) | 10 |
| Plains lovegrass (<i>Eragrostis intermedia</i>) | 5 |
| Milkvetch (<i>Astragalus nuttalliana</i>) | 5 |
| Horsepurslane (<i>Trianthema</i> sp.) | 5 |
| Barrel cactus (<i>Ferocactus</i> sp.) | 5 |
| Globemallow (<i>Sphaeralcea</i> sp.) | 5 |
| Wild gourd (<i>Cucurbita digitata</i> or <i>C. foetidissima</i>) | 5 |

chia, milkvetch, horsepurslane, barrel cactus, an unidentified monocot, globemallow, and wild gourd. Many of these taxa are available during late summer and early fall. *Astragalus* fruits in spring (February to May), and some taxa are available for extended periods from spring through late fall or early winter, including globemallow, barrel cactus, and chia. Thus the ethnobotanical data suggest that farmers relying on a mixed diet of maize and a variety of wild taxa occupied the site at least during the spring, summer, and fall (Hanselka 2000).

Gayle Fritz identified the only other possible cultigen, potentially domesticated amaranth (Fritz et al. 1999), based on scanning electron microscope (SEM) analysis of seed coat thickness. She notes that all of the charred amaranth seeds examined under the SEM have the thin seed coats that are characteristic of domesticated grain amaranth. This finding suggests that future researchers should strive to document the presence of domesticated amaranth during the Archaic period. It is most likely that domesticated amaranth diffused northward from Mesoamerica along with maize and other cultigens.

Wood charcoal taxa found both during excavation and in the flotation samples were mostly mesquite (*Prosopis* sp.), but also included such woody taxa as walnut (*Juglans* sp.), cottonwood/willow (*Populus/Salix*), saltbush (*Atriplex* sp.), and juniper (*Juniperus* sp.). The occasional presence of ocotillo (*Fouquieria* sp.) charcoal suggests it may have been used as construction material. Grass (Gramineae) stems may represent construction material or remains from food processing. The charcoal record suggests that in prehistoric times the environment surrounding Cerro Juanaqueña supported an assemblage of plants similar to those found in the area today. The prevalence of *Prosopis* charcoal in the archaeological record suggests the common use of mesquite wood as fuel.

The evidence suggests that the occupation of Cerro Juanaqueña was at least

relatively sedentary and that maize was a dietary staple. Many of the standard indicators of sedentary occupations are present, including substantial household trash accumulations, significant labor investment, site planning, and storage pits. The ground stone assemblage indicates intensive food processing, and the large metates represent nonportable site furniture. About ten isolated human bone fragments have been found, suggesting the presence of as-yet-undiscovered burials. The ethnobotanical spectra represent plants that are harvested from spring until fall. The quantities of maize and amaranth we have recovered indicate that crops were grown at this location, implying occupation through the growing season, from late June through mid-October. (With irrigation, maize could have been planted as early as April and harvested by mid-August.) Substantial use of maize and evidence of food storage is often interpreted as an indicator of winter and early spring occupation. Cerro Juanaqueña represents an occupation size and duration greater than the nondomesticated resources of the region could support. Clearly maize and amaranth were significant in the diet, and tending these crops limited mobility. It is likely that the occupants of Cerro Juanaqueña resided there most of the year, perhaps on the order of nine months annually. However, both limited seasonal abandonment and year-round occupation are compatible with the evidence.

The combined estimated total of 20,000 person-years of site use, the occupation span of 100–500 years, and nine months/year residence result in a series of alternative occupation models. The one we favor suggests that Cerro Juanaqueña was occupied for about 200 years by about 200 people who engaged in intensive food-processing activities (and thus generated metate wear) for about six months of the year (see Roney and Hard 2002).

Optimal Foraging Theory and the Transition to Farming

Cerro Juanaqueña and the other Late Archaic *cerros de trincheras* sites are interesting in their own right, but they are especially important because of their bearing on the initial diffusion of agriculture into North America. The questions posed by chapters in this volume concern the processes of diffusion and adaptation. Why was farming integrated into the economy rapidly in some places and far more slowly in others? The answer to this question depends upon how we model the initial spread of agriculture. Two fundamentally different processes have been proposed to describe the diffusion of agriculture into the Southwestern United States. A long-standing model holds that between 3000 and 4000 BP there was a more or less continuous distribution of low-level preagricultural foraging groups between Mesoamerica and the Southwest. It is thought that seeds and knowledge of agriculture were transmitted from one band to

another, eventually reaching the Southwestern United States. Currently there are a number of different processual models suggesting why increased reliance on maize occurred and implicating various push and pull factors. Another approach (most recently articulated by Berry 1982; Hill 2001; Huckell 1995; and Matson 1991) envisions agriculture, at least in part, spreading by actual migration of agriculturalists. These differing points of view parallel discussions surrounding the diffusion of agriculture in other parts of the world. In this context Southwestern North America (Northwest Mexico and the U.S. Southwest) is important as a case study with potential relevance to wider issues.

The two different models have very different implications for our understanding of early agriculture in Southwestern North America. Unfortunately it is very difficult to distinguish between these two alternatives on the basis of archaeological evidence alone; at this point we advocate development of explanatory frameworks that do not, *a priori*, eliminate either alternative. In northwestern Chihuahua we are exploring this approach by attempting trial formulations that integrate a variety of ecological approaches. Optimal foraging models in particular have utility in this context, as these models suggest that people selected an optimal adaptation to a region whether they were newly arrived immigrants or an indigenous population. An optimality approach also assumes that neither push nor pull factors have preeminence but suggests that the dietary mix that yields the highest return rate will be selected.

Optimal Foraging Theory

Optimal foraging theory's diet-breadth model has utility, because it specifies when an item may be included in the diet. It relies on two independent variables: search costs and processing costs. Search costs are considered to be a function of resource density, as the model assumes random searching. As the density of higher-return-rate items declines, their search costs increase. Processing costs involve the pursuit and handling costs related to the difficulty of obtaining a resource and converting it to an edible form relative to its caloric return. Typically foods are ranked according to their postencounter return rates. The overall foraging efficiency of the diet, however, includes search costs as well as pursuit and handling costs for all items in the diet. An additional, lower-ranked item may then be added to the diet upon encounter if its addition results in an increase in overall foraging efficiency. The model assumes that an item in the optimal diet will always be taken whenever it is encountered (e.g., Barlow 1997, 2002; Winterhalder and Goland 1997). Although the diet-breadth model does not directly address the issue of importance of an item in the diet, the degree to which that item is utilized is related to the *density of higher-ranked*

items as well as that item. An additional factor to consider with the diet-breadth model is risk reduction.

One approach to consideration of risk models foragers' contingency decisions as related to potential risks and payoffs is the Z-score model. The Z-score model suggests that foragers will choose a set of resources based on three variables: average return rate, variability, and minimal requirements. The goal is not to fall below the minimal requirements (Winterhalder and Goland 1997:136). If the potential mean yield of resource options is greater than the minimal needs then survival may be enhanced by choosing the resource option that is more predictable (with lower variance). Alternatively, if the minimal needs exceed the average yield of resource options then the higher variance resource would be selected, betting on the potential of riskier yet greater returns that may meet minimal requirements (Winterhalder and Goland 1997). In the effort to reduce risk, there is frequently a reduction in average foraging efficiency.

The Z-score model is only modeling the choices of a single individual or a group of individuals engaging in the same behaviors. Foragers, however, overcome this constraint through four other risk reduction strategies: intraband sharing, sexual division of labor, reciprocal access, and storage. Intraband sharing allows members to pursue alternative resources and then pool the products, thereby offsetting short-term variable returns (Kaplan and Hill 1985; Winterhalder 1986; Winterhalder and Goland 1997). Sexual division of labor may allow men vs. women to pursue prey with differing levels of risk. If resources fail throughout a band's territory, then movement to another territory, perhaps through systems of reciprocal access, can offset regional variability (Winterhalder and Goland 1997). Storage also offsets regular periods of scarcity and abundance that are common in temperate environments. Farmers utilize analogous risk reduction strategies through systems of dispersed fields that offset local stochastic fluctuations in yields (Winterhalder and Goland 1997).

Do the diet-breadth model and associated risk-reduction models, with their focus on resource ranking, density, and variability, have utility in understanding the initial adoption of maize and increasing use of maize? In the American Southwest and Northwest Mexico widespread use of maize was underway shortly after its introduction. Throughout most of Arizona and New Mexico maize played only a minor role in the diet from ca. 1300 BC to ca. AD 100–750 and even later when more sedentary, agrarian communities became widely established (Hard et al. 1996). In the Tucson Basin, southeastern Arizona, and northwestern Chihuahua, however, maize farming quickly became a major part of the diet, and farming communities, including Cerro Juanaqueña, were established by 1200 BC. In contrast, only 30–200 km to the northeast, in the Southern Jornada Mogollon region, farming economies were not established

until ca. AD 1000–1200 (Hard 1997; Hard et al. 1996; O’Laughlin 1980; Whalen 1994). Behavioral ecology can provide explanatory models, testable predictions, and relevant variables and define the kinds of evidence needed to explore the variability in the degree and timing of greater levels of maize dependence. As an exploratory use of optimal foraging models, we offer the initial component of a comparison between the Río Casas Grandes and Southern Jornada regions. These two regions represent the extremes of the timing of the formation of farming economies in the Southwest. Yet they both have major streams and are both in the Chihuahuan biotic province, a few days’ walk from one another (see Doleman, this volume, for another approach to consideration of the Jornada region).

The diet-breadth model indicates that when a resource is in the optimal diet the frequency with which it is used will be related to the density of higher-ranked resources. If resources with greater return rates than maize are plentiful in the landscape, they should be taken upon encounter, and therefore greater use of lower ranked maize is unnecessary even if maize farming is rather productive.

Ranking Agriculture

Renee Barlow (1997, 2002) has examined the costs and return rates of subsistence maize-based agriculture, utilizing detailed ethnographic accounts from Chiapas and Guatemala to derive return rates that are inversely related to increasing maize field investment. The Mesoamerican yield data appear roughly applicable to the North American Southwest. Barlow’s (1997:101) data suggest that the mean yield for all the Chiapas and Guatemala production is 1,390 kg/ha ($n = 112$, std. dev. = 553 kg/ha). Risa Arbolino’s (2001:72) data indicates the average irrigated field corn yield for 22 northern U.S. Southwest Native American groups is 1,151 kg/ha ($n = 46$, std. dev. = 402 kg/ha). Southwestern yields of other varieties of maize, including ancient ones, may have been less, however, and maize was grown under more variable circumstances than these data suggest (Arbolino 2001). For example, runoff fields below 5,500 ft in elevation produce an average of only 688 kg/ha, and those above 5,500 ft produce 981 kg/ha. Nonetheless, as a starting point to model maize return rates Barlow’s study is one of the best currently available.

Barlow models four levels of labor investment in maize farming. The first is the plant and harvest strategy that may produce relatively low yields of 2–5 bu/acre (125–314 kg/ha) with a labor investment of approximately 50 hr/acre, yielding a relatively high return rate of 1,300–1,700 kcal/hour (Figure 6.7).

Return Rates Wild & Maize

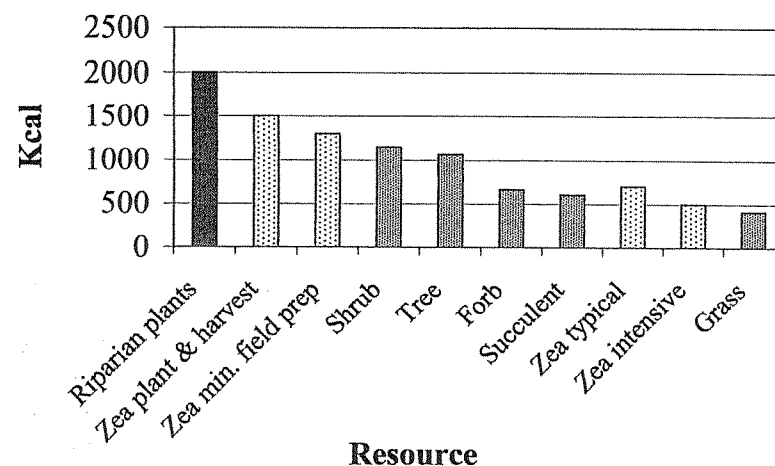


Figure 6.7. Average return rates of nondomesticated plant lifeforms and maize at varying levels of investment (Barlow 1997, 2002; Dering 1999; Doelle 1976; Simms 1986, 1987). Sample sizes: riparian, $n = 1$; trees, $n = 2$; shrubs, $n = 2$; succulents, $n = 2$; forbs, $n = 5$; and grasses, $n = 2$.

Minor investment in maize utilizing a plant and harvest strategy should occur when taxa ranked higher than 1,300–1,700 kcal/hr, such as cattail pollen and roots and most mammals, become limited in availability during parts of the year. If resources with similar or lower return rates (such as pine nuts or bulrush seeds) are included in the diet, then minor use of maize is expected as well.

The next greater level of investment is characterized as slash and burn farming: it involves greater land clearing and field preparation activities before planting but no substantial work during the growing season. In productive, well-watered settings energetic return rates of approximately 1,100–1,500 kcal/hour with yields of 5–15 bu/acre (314–941 kg/ha) and field investments of 150–250 hr/acre may be achieved (Barlow 1997, 2002). Although slash and burn farming was probably not a widely used strategy in the North American Southwest, it is representative of an intermediate investment in fields, involving initial field preparation but little investment after planting. Other strategies such as floodplain farming may also yield these returns.

If conditions are present for such a low-investment productive strategy,

it should be pursued with the decline of higher-ranked resources such as pine nuts and bulrush. Accompanying this strategy would be the inclusion of resources such as mesquite, saltbush, and tanseymustard that have return rates of 1,000–1,300 kcal/hr.

Greater investment in agriculture would also be contingent on the local ecological conditions that would allow increased yield relative to time invested (Barlow 1997, 2002). The shift from a plant and harvest strategy to an intermediate (slash and burn-like) level of investment represents perhaps the most critical shift in the evolution of Southwestern farming economies. Barlow (2002) suggests that the Late Archaic farming settlements in the Tucson Basin may represent this level of investment, as well as such early pithouse settlements as the SU site and Basketmaker II sites on Cedar Mesa.

Greater field investment than that of an intermediate strategy is expected to yield declining marginal returns, as represented by the third strategy, which is known as “typical” maize farming. If the better local conditions needed to support an intermediate strategy are not available, a typical maize farming economy could emerge directly from a plant and harvest strategy. Typical maize farming was commonly conducted in the Greater Southwest among most full-time agriculturalists. In Guatemala and Chiapas these maize fields yielded widely varying return rates of 300–1,100 kcal/hr, suggesting that local farming conditions play a significant role in return rates. Analogous prehistoric return rates for well-watered southwestern Colorado are estimated to be 700–900 kcal/hr with yields of 2–20 bu/acre (125–1,254 kg/ha), with field investments of 400 hr/acre (Burns 1983, as cited by Barlow 1997). In the Fremont region return rates were probably even lower (Barlow 1997, 2002). Greater investment in typical farming fields should increase as the availability of such higher-return items such as mesquite and saltbush declines. Nondomesticated taxa that should be added with this farming strategy include acorns, bluegrass, wild sunflower, Indian rice-grass, agave, and sotol. Other small-seeded resources such as amaranth and goosefoot may be included with this group as well, although data are lacking (Barlow 2002).

The final and most intensive farming strategy in Barlow's scheme yielded 850 kcal/hr in Guatemala and is considered to be rare in the Fremont region and the Southwest. Yields under 500 kcal/hr are expected in the West, with field investments on the order of 800 hr/acre and yields on the order of 12 bu/acre (752 kg/ha). Such strategies should only be adopted under stress conditions with the depletion of higher-ranked wild resources. The use of the lowest-ranked nondomesticated resources should be included as part of this strategy, including dropseed, pickleweed, squirrel-tail grass, and some species of wild barley that have return rates of ca. 100–300 kcal/hr (Barlow 1997, 2002).

The Southwest

Are these expectations useful for understanding the variability in the adoption of agriculture in the Southwest? The rapid integration of the plant and harvest strategy across the Southwest at ca. 1000 BC (e.g., Hard and Roney 1998a; Haury 1962; Huckell 1995, 1997; Matson 1991; Minnis 1992; Smiley 1994; Wills 1988) is compatible with the expectations of the model. This level of investment offers higher return rates than many arid land seed resources. Ethnobotanical studies show that many intermediate- to low-return rate resources were a common part of the diet during the Late Archaic period. For example, grama grass (*Bouteloua*), dropseed grass (*Sporobolus*), and New Mexico feather grass (*Stipa neomexicana*) were commonly recovered from the Late Archaic levels at Fresno Shelter (Bohrer 1981). A plant and harvest maize strategy yields a return rate higher than these resources, so the diet-breadth model suggests that maize should have been added to the diet as soon as it was available, particularly since maize and wild grasses have a similar seasonality. Thus the rapid integration of a plant and harvest farming strategy across the Southwest as soon as maize was available is compatible with the model (Barlow 2002).

Are the different investments in farming in the Río Casas Grandes region and the Southern Jornada region also understandable in terms of this model? We would expect that the Río Casas Grandes region's rapid shift to substantial farming would correlate with lower availability of high-return resources relative to the potential returns obtained by further investment in farming. In contrast, the Southern Jornada Mogollon region's delayed shift to farming should correlate with greater availability of dense, high-return resources relative to the potential return rates from farming. Risk-reduction strategies and relative return rates of farming are likely to have played a role in these options as well. In order to evaluate these hypotheses we will consider elements of the resource structure of each region. The two regions both have a water-controlled environment, Basin and Range topography, a major stream, similar Lower Chihuahuan Life Zone ecology, variable, summer-dominant rainfall, and a similar paleoenvironmental sequence and presumably had access to similar maize-farming technologies.

The differences are that the Jornada area receives only 23.3 cm (std. dev. = 6.9 cm, $n = 34$ years) of annual rainfall and is situated in the Chihuahuan Desertscrub biotic community, with some areas of Semidesert Grassland (Brown 1982b, 1982c; Brown and Lowe 1983). In contrast, the Río Casas Grandes region receives 50% more summer rainfall, for an annual average of 33.4 cm (std. dev. = 9.1 cm; $n = 32$), with two-thirds falling between July and October. It is situated at the base of the Sierra Madre Occidental in grasslands, with Semidesert Grass-

lands to the east and Plains Grasslands to the west (Brown and Lowe 1983). The paleoecological sequence incorporating both regions is reviewed first.

Paleoecology

In recent years a series of paleoecological studies from within a surrounding radius of 250 km from Cerro Juanaqueña (Figure 6.1) has been completed (Buck and Monger 1999; Castiglia 2002; Fleischauer and Stone 1982; Krider 1998; Metcalfe et al. 1997; Ortega-Ramírez 1995a, 1995b; Urrutia-Fucugauchi et al. 1997; Van Devender 1990, 1995; Van Devender and Worthington 1977; Waters 1989). In addition Lee Nordt (2003) developed an alluvial and isotopic sequence for the Río Casas Grandes below Cerro Juanaqueña as an element of our project. These studies consist of an array of stratigraphic, sedimentological, geomorphic, rock-magnetic, isotopic, and pack-rat midden studies. Combined, these studies offer a consistent picture of the paleoenvironment. The following paleoenvironmental summary uses radiocarbon years BP for all dates except where otherwise noted.

The Late Wisconsin pluvial period was cool and wet, with greater winter rainfall maintaining water in playas including Lake Cochise, Babicora Lake, Encinillas Basin, Cloverdale Lake, Playas Lake, and Lake Palomas. Warm, wet, pluvial conditions existed during the early Holocene, although the drying and refilling of Lake Cochise suggests variability (Waters 1989).

By the early Holocene a brief period of lake shallowing occurred in the Babicora Basin between 11,060 and 9470 BP, correlating with the Younger Dryas (Metcalfe et al. 1997). Grasslands dominated the Tularosa Basin (Buck and Monger 1999), and oak juniper woodlands were present on the Hueco Mountain slopes near El Paso (Van Devender 1995). Grasslands in the highlands of Lake Babicora slowly replaced woodlands during the early Holocene.

After 9000 BP, during the middle Holocene, a widespread period of somewhat drier conditions prevailed, as winter rains lost their dominance to summer. Lake Cochise was dry (Waters 1989); the lowland Tularosa Basin vegetation shifted from grassland to shrublands (Buck and Monger 1999); and the Hueco Mountain slopes vegetation shifted from an oak-juniper woodland to grassland (Van Devender 1990). Grasslands also replaced woodlands in the highlands of the Babicora Basin as a result of warmer, drier conditions. These generally drier conditions were not uniform.

Pluvial Lake Palomas filled again around 8500 BP (Castiglia 2002). The Babicora and Encinillas Lakes are thought to have held water until ca. 7000 BP (Metcalfe et al. 1997). The Laguna El Fresnal portion of Lake Palomas Basin filled again about 6000 BP (Castiglia 2002). Lake Cochise also filled and dried

again at ca. 5400 BP (Waters 1989). Possibly two other lake stands took place during the middle Holocene in the Animas Valley (Fleischauer and Stone 1982). Summer monsoons supported grasslands in the Playas Valley, and that lake contained perennial water until 4000 BP (Van Devender 1995; Van Devender and Worthington 1977). Evidence from the Babicora Basin indicates a mid-Holocene period of generally decreased rainfall, although marshes were extant (Metcalfe et al. 1997; Ortega-Ramírez 1995b). In the Río Casas Grandes a plant community consisting of about 60% C_4 grasses formed (Nordt 2003). Perhaps decreased winter moisture and warmer summer temperatures can account for vegetation shifts that suggest increased aridity (including woodland to grassland vegetation shifts at higher elevations and increasing shrublands in the Tularosa Basin), although a regime of high-magnitude floods was underway by ca. 5000 BP.

In the late Holocene another widespread shift occurred over much of the Southwest, bringing moister conditions, continuation of notable high stands, and high-magnitude floods between 5000 and 4000 BP (Ely 1997). In the Río Casas Grandes an erosional event at 5000 BP and deeply entrenched channels are consistent with high-magnitude floods (Nordt 2003). A 4000 BP late Holocene beach ridge at Laguna El Fresnal marks another filling event, on par with the middle Holocene one (Castiglia 2002). Sometime between ca. 4000 and 3000 BP Lake Cochise also filled again (Waters 1989). A deep-water lake refilled in the Babicora Basin and for a brief period resembled Late Pleistocene conditions (Metcalfe et al. 1997:169). Cloverdale Lake also filled. The dating of the Lake Cochise, Babicora Basin, and Cloverdale Lake high stands is imprecise, so correlations with the Southwest-wide high-magnitude floods are unknown. Grasslands continued to dominate in the Río Casas Grandes region and returned to the Tularosa Basin after 4000 BP. Paleosol formation and floodplain building in Río Casas Grandes by 3100 BP correlates with the pronounced absence of high-magnitude floods across the Southwest between 3600 and 2200 BP (Ely 1997; Nordt 2003). The earliest ^{14}C date from the site of Cerro Juanaqueña is 3130 ± 55 b.p., indicating that people began inhabiting the site contemporaneously with the formation of the Trincheras paleosol with a date of 3140 ± 100 b.p. This time appears to mark a pivotal shift in paleoclimate following the cessation of high-magnitude floods after 3400 BP (Ely 1997).

Although high-magnitude floods were absent, moisture levels at ca. 3000 BP may have been relatively high. Southeastern Arizona alluvial stratigraphic studies suggest mesic late Holocene conditions (Mehring et al. 1967). Data from the San Juan Basin of New Mexico and the Mogollon Highlands of Arizona also suggest that ca. 3000 BP was a moist period (Smith and McFaul 1997; Waters and Haynes 2001). Stalagmite records from the Guadalupe Mountains in southern

New Mexico indicate slightly greater effective moisture between 4000 and 3000 BP and significantly greater moisture in 3000–1700 BP (Polyak and Asmerom 2001). D. E. Wilkens and D. R. Currey (1999) also report a moist interval in the Guadalupe Mountains dated to 3400 BP. Although T. R. Van Devender (1990) does not report a more mesic interval during the late Holocene, a close examination of packrat-midden spectra from the El Paso region's Hueco Mountain slopes suggests a brief return to more mesic species and a decline in desert shrubs and succulents between 3000 and 1700 BP (Mauldin 1995). Moisture at Playa Lake was sufficient to support chub-type fish and salamanders found in raptor deposits and constrained by ^{14}C dates of 3300 and 2400 BP (Van Devender and Worthington 1977). In the Babicora Basin high effective humidity is suggested by marsh deposits and paleosols dating between 3800 and 2800 BP (Ortega-Ramírez et al. 1998:1177).

After 3000 BP an overall drying trend occurs, although pronounced floodplain building in the Río Casas Grandes resumed, consistent with the absence of high-magnitude and erosive flooding until ca. 2200 BP (Nordt 2003). The vegetation in the Río Casas Grandes continued to be dominated by grasslands, but Lake Cochise remained dry (Waters 1989). In the Babicora Basin modern semiarid conditions became established after 3000 BP (Ortega-Ramírez 1995b). S. E. Metcalfe et al.'s. (1997) Babicora study indicates that a shallowing of the lake occurred before 2470 BP. One Babicora sequence tentatively suggests that drying conditions were underway as early as 3070 BP (Metcalfe et al. 1997). In the Tularosa Basin vegetation shifted to a modern C_3 -dominated shrublands, and desert shrublands were established on the Hueco Mountain slopes (Buck and Monger 1999; Van Devender 1990).

A return to cooler, wetter conditions occurred in the highlands of Lake Babicora after 2000 BP. Cerro Juanaqueña was reoccupied at ca. 2200 BP, which correlates with the formation of the Janos paleosol, also dated to 2200–2000 BP. A continued absence of high-magnitude flooding, landscape stability, and C_4 -grassland dominance on the Río Casas Grandes are similar to the conditions during the original occupation of Cerro Juanaqueña. Cerro Juanaqueña was abandoned again about the same time that high-magnitude flooding resumed at ca. 2000 BP that is marked by an erosional event (Nordt 2003). The high-magnitude flooding regime persisted until ca. 1100 BP. This may correlate with the expansion of cienega aquatic vegetation at 1400–1800 BP and the refilling of Playa Lake at 1000 BP (Krider 1998). This period of high-magnitude flooding came to an end after ca. 1100 BP, correlating with a warmer and drier interlude at Lake Babicora (Nordt 2003). Grasslands continued to dominate in the Río Casas Grandes Valley (Nordt 2003). A cooler and wetter shift is recorded at Lake

Babicora at ca. 500 BP during a resumption of high-magnitude flooding. This correlates with another refilling of Playa Lake at ca. 300–500 BP (Krider 1998).

In summary, these studies suggest that elements of a cool, wet Late Wisconsin continued into the early Holocene, although localized periods of drying occurred. Drying conditions were widespread by the middle Holocene, albeit with some periods of increased moisture. A period of high-magnitude floods dominated the Southwest between ca. 5000 and 3600 BP, resulting in filling and deposition in the playas in the Río Casas Grandes. Southwestern high-magnitude flooding decreased markedly between 3600 and 2200 BP. Although overall moisture regimes at ca. 3000 BP remained high, the following millennium witnessed a slow drying trend. Cerro Juanaqueña was first occupied at an apparently ideal time, following a long period of floodplain building. Moisture levels were generally high, but there was an absence of high-magnitude floods. Cerro Juanaqueña was abandoned after about two centuries of occupation but reoccupied and abandoned before the high-magnitude flood regime returned at ca. 2000 BP in the Río Casas Grandes Valley. The remaining late Holocene was generally similar to today, but with some isolated periods of increased summer rainfall.

Modern Ecology

According to late nineteenth century reports grama grasslands were highly productive in the southern desert basins. Shrub invasion and desertification was underway by the end of the nineteenth century, a process that appears to be continuing today (e.g. Dick-Peddie 1993; Van Auken 2000; York and Dick-Peddie 1969). Overgrazing is given as the primary cause, but a number of studies suggest that historic declines in rainfall may also have played a role.

The dynamic paleoecology of southern New Mexico and northwestern Chihuahua reflects marked fluctuations between grassland and shrubland throughout the Holocene as moisture regimes vacillated. The geographic settings of the two study regions, however, ensured that because of its higher altitude and closer proximity to the Sierra Madre Occidental the Río Casas Grandes region always received higher levels of summer precipitation than the Southern Jornada region. The modern vegetation map for the Southwest (Brown and Lowe 1983) indicates that Chihuahuan Desertscrub dominates the Southern Jornada region, with a lesser proportion of Semiarid Grassland in the higher elevations.

Semiarid Grassland to the east and Plains Grassland to the west dominate the Río Casas Grandes region. The Semidesert Grassland is a transitional com-

munity lying between the Plains Grassland and the Chihuahuan Desertscrub (Brown 1982c:127). Semidesert Grasslands are best viewed as a fluctuating continuum from desert grasslands to shrublands, related to shifts in precipitation patterns and historic overgrazing. Higher levels of rainfall and deep soils tend to enhance the density of grasses in relationship to shrubs (Brown 1982c). Under climax conditions perennial bunch grasses are interspersed with bare ground. Adequate rainfall, minimal erosion, and deep soils allow perennial grasses to cover vast expanses. Under low summer rainfall conditions, annuals increase at the expense of perennial grasses (Brown 1982c:124; Burgess 1995).

To the west, between 1,400 to 1,500 m, is the Plains variant of the Plains and Great Basin Grassland biotic community (Brown and Lowe 1983). Plains Grasslands border woodland vegetation above ca. 1,500 m and Semidesert Grassland below ca. 1,400 m. Grazing has resulted in shrub invasion; areas that were Plains Grassland have become Semidesert Grassland, and transitions between the two are subtle. In climax conditions this biotic community is composed almost entirely of grasses, with forbs and shrubs constituting less than 10% (Heerwagen 1956, as cited by Dick-Peddie 1993).

A complete evaluation of the utility of the diet-breadth model requires assessment of the density, spatial and temporal distribution of plant and animal resources, and return rates, as exemplified by David Zeanah and his colleagues (1995). Such an ambitious undertaking is far beyond the scope of this study. An initial assessment of nondomesticated food availability is attempted here by simply examining the relative quantity of nondomesticated food plants in each biotic community. Rough consideration of return rates is based on plant lifeform (shrubs, forbs, etc.). We consider farming return rates, based on the work by Barlow and considering local geographic and ecological factors.

Nondomesticated Resources

Optimal foraging theory ranks food resources by their postencounter return rates. Mammals have the highest return rates, and they decline with body size. Artiodactyls and lagomorphs were the major species utilized in both regions, with return rates on the order of 10,000 kcal/hour or more (e.g., Barlow 1997). The similarity of the two environments, the taxa present, and the faunal assemblages found in each region suggests that differential plant availability may be playing a more critical role in the formation of farming economies than animals do. Consideration of plant return rates is our initial concern.

Only a small number of Southwestern plants have been analyzed for return rates, but return rates are somewhat related to lifeform (Zeanah et al. 1995). Return rate data for taxa that are found in these regions were accumulated from

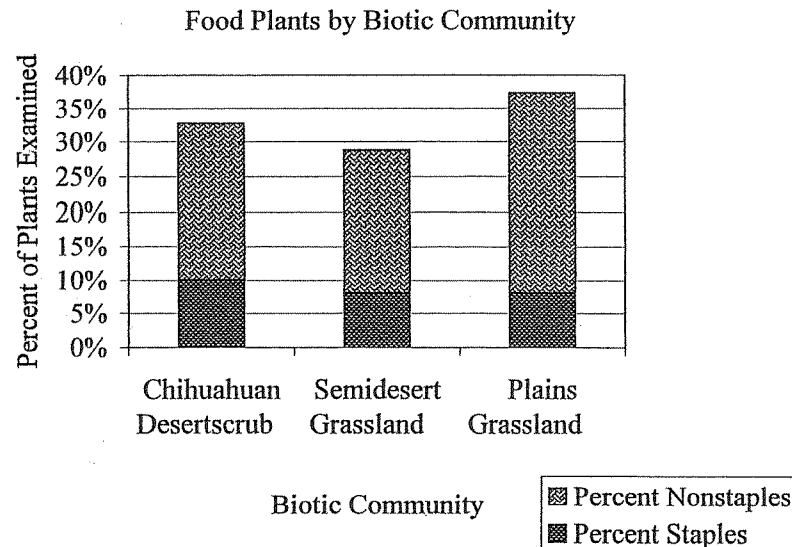


Figure 6.8. Percent staples and nonstaples of nondomesticated plants by biotic community. Percentages are remarkably consistent across communities. Total species examined: Chihuahuan Desertscrub, $n = 119$; Semidesert Grassland, $n = 247$; Plains Grassland, $n = 123$.

studies from the Great Basin plus additional data on mesquite and succulents (Barlow 1997; Dering 1999; Doelle 1976; Simms 1986, 1987). Figure 6.7 shows average return rates by major plant lifeform. Return rates decline in the following order: riparian plants, shrubs, nuts, forbs, succulents, and grasses. Note that these are based on small sample sizes.

Under optimal foraging theory the availability of wild plant foods is a factor in the formation of farming economies. In the absence of more detailed plant density and distribution data, we evaluated the relative number of consumable plants in the Chihuahuan Desert Shrubland, Plains Grassland, and Semidesert Grassland biotic communities (Brown and Lowe 1983). The scientific names of 429 plant species from plant inventories for each biotic community (Brown 1982a; Dick-Peddie 1993) were entered into David Moerman's (2001) massive web-based North American Ethnobotany Database. Compiling these data produced a list of food plants, their lifeform, and if they were used as staples. Virtually all identifications were at the species level, with a few matches at the genus level.

The results presented in Figure 6.8 suggest there is little difference in the frequency of staples or total edible plants among the Southern Jornada Mogol-

Life Forms & Biotic Communities

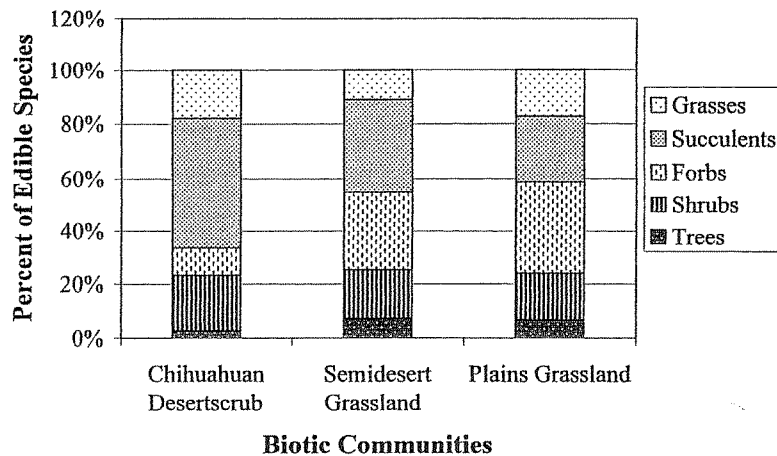


Figure 6.9. Proportion of lifeforms of edible plants by biotic community. Trees are negligible, and shrubs and grasses are similar across communities. The sum of succulents and forbs is similar across communities, and both lifeforms have similar return rates. This chart suggests that in considering only edible species inventories in the three communities there is little difference in overall proportions of lifeforms. Therefore the return rates of the edible plant assemblages from each community are similar. This, however, does not consider plant density or distribution.

lon Chihuahuan Desertscrub and the two grassland communities that characterize the Río Casas Grandes region. In all three, 8 to 10% of all taxa evaluated were staples. Between 29 and 37% of all plants in each of the three communities are food sources. Since lifeforms are related to return rates, are there major differences in the frequency of the lifeforms of edible taxa among the biotic communities?

The stacked bars in Figure 6.9 represent the lifeform proportions of the 156 edible species from the three biotic communities. Trees are negligible in all three. The frequency of edible shrub species is similar across the shrublands and grasslands. Forbs and succulents, which have similar return rates, constitute a large group of alternate resources; and these two lifeforms can be summed for analytical purposes. The sum of the edible succulent and forb frequencies for all three communities is similar across the three communities.

In summary, this vegetation analysis shows that the frequency of edible species, lifeforms, and staples among the Chihuahuan Desertscrub, Plains Grass-

land, and Semidesert Grassland is similar. We cannot fully consider differential plant density, seasonality, and habitat variability here, additional factors that could significantly affect wild plant resource availability. The descriptions of these biotic communities and the absence of quantifiable information for the Río Casas Grandes region do not allow us to address relative densities of forbs and succulents in the two regions. It is likely the densities of edible shrubs such as mesquite and saltbush were indeed greater in the Chihuahuan Desertscrub biotic community than in the Semidesert Grassland and Plains Grassland (e.g., Brown 1982b, 1982c; Burgess 1995; Dick-Peddie 1993) throughout the Holocene. Riparian habitats as well as bajadas, in both the grasslands and the desertscrub communities, would support significant stands of mesquite and other shrubs.

Farming Potential

Low-investment plant and harvest farming strategies appear to have been ubiquitous across the Southwest during the Late Archaic period. In most places, however, these small fields were not very productive and yielded only a minor part of the diet. In contrast, did the Río Casas Grandes floodplain support high-return, intermediate-investment maize farming that generated sufficient yields, allowing maize to play a larger role in the diet? If so, maize fields would have become a high-density, high-return resource. Under those conditions lower-return foods such as forbs, succulents, and grasses should have played a relatively minor role in the diet and should have been used only when maize was limited in availability.

Alternatively maize farming at Cerro Juanaqueña may have been of the more typical variety, with return rates roughly on a par with forbs and succulents. At this point it is difficult to distinguish between the intermediate and typical alternatives, and both are briefly considered here. The range of farming technologies available to the occupants of Cerro Juanaqueña included dry-farming (rain-fed) fields, floodplain fields, water-table fields, seepage fields, irrigated fields, and *ak chin* (a method of placing fields to take advantage of runoff) fields (Glassow 1980). Next we review these options and their potential return rates.

Dry-farming or rain-fed fields are dependent upon direct moisture falling on the fields (Doolittle 2000). Maize requires about 50 cm of moisture for optimal growth, but a minimal crop can be produced with as little as 15 cm of summer rainfall (Rhode 1995; Shaw 1988). Modern growing season rainfall at Janos is 21.9 cm (std. dev. = 7.7 cm, $n = 33$ years), which suggests that in most years growing season (July–October) rainfall would exceed the minimum.

Dry farming should routinely produce a minimal crop but would rarely produce an optimal crop. In fact, local farmers now living in the vicinity of Cerro Juanaqueña report that rain-fed farming, combined with only occasional irrigation in dry years, was the primary agricultural strategy until recently. They planted maize in May, relying on winter moisture for germination and summer rains for plant growth and cob formation. The onset of an extended drought in the early 1990s reduced reliance on rainfall and forced greater use of spring-fed irrigation and pumping from the river. By the late 1990s these surface water sources had dried, and underground pumping of irrigation water became the only viable approach. Higher moisture levels 3,000 years ago likely would have enhanced the success of dry farming significantly, reducing its risk.

Floodplain fields along the Río Casas Grandes could potentially be watered by over-bank sheet floods that spread over the floodplain, an approach known as flood-recession agriculture. Modern farmers indicate that this is not a principal source of moisture today, apparently because it is unreliable. Rainfall must be sufficient for over-bank floods, the maize plants must be tall enough to withstand the drenching, and water velocity and sediment loads must be minimal to avoid damaging the crop. In 1999, after several days of strong July thunderstorms, we witnessed the Río Casas Grandes leave its banks and spread over the first alluvial terrace, leaving only a thin veneer of sediment.

The valley bottom below Cerro Juanaqueña appears to be suited for this type of farming: the wide floodplain allows floodwaters to decelerate rapidly, particularly since just downstream the Río Casas Grandes constriction slows stream velocity and forms a flood basin. The Trincheras paleosol probably was the floodplain used for farming ca. 3,000 years ago. Its fine sediment and the absence of gravels suggest that flooding was not flashy, yet its water-holding capacity was good (Nordt 2003). Prior to ca. 3100 BP and the occupation of Cerro Juanaqueña, the floodplain was aggrading under a regime of high-magnitude floods. The formation of the Trincheras paleosol also suggests landscape stability and absence of high-magnitude flooding (Nordt 2003). Across the Southwest high-magnitude floods ceased between 3600 and 2200 BP (Ely 1997), although regional paleoenvironmental reconstructions indicate that moisture levels were higher than today.

Farming based on high water tables or seeps is one of the most dependable strategies. In parts of the floodplain the water table would have been accessible at times by maize taproots. Some maize varieties such as Hopi Blue Corn can penetrate 3 or 4 m, and a 2-m reach is not uncommon. However, the plant must grow sufficiently before the roots reach that length. In addition maize is susceptible to anaerobiosis if water levels are within the root zone for extended

periods. Water levels should be below 1 m to provide adequate moisture without interfering with the flow of oxygen (Nordt 2003).

The redoximorphic features of Trincheras floodplain soil indicate that it experienced a high water table, but one that fluctuated and was not permanently elevated. Between 1997 and 2000 backhoe trenches found the modern water table between 0.5 and 3 m deep, varying with terrace surface (Nordt 2003). The spring at the base of Cerro Juanaqueña is indicative of a high water table, and Donald Brand (1937) noted that in the 1930s springs were common along the Río Casas Grandes. The constriction of the valley may also act to force groundwater closer to the surface. Today farmers do not include water-table farming as a strategy, although in principle it could potentially be successful, given some water table depths. Local inhabitants indicate that the water table fluctuates substantially and can be unpredictable; presumably drought and groundwater pumping affect it. For example, a 4 m deep well in the floodplain recently dried, as did the spring. The individuals we spoke with did not appear to be aware of the correlation between modern alluvial terrace location and water table depth.

Finally, while we have no direct evidence, the existence of irrigation canals by the occupants of Cerro Juanaqueña cannot be eliminated. Irrigation canals would certainly be within the scope of building projects that the occupants of Cerro Juanaqueña could design and build, and 3,000-year-old canals have been found in the Tucson Basin (Mabry 2002). *Ak chin* fields could have been planted, particularly where arroyos empty onto alluvial fans to take advantage of spreading rainfall runoff. Settings suitable for *ak chin* farming exist along the margins of the floodplain.

What farming strategies did the Native Americans of Cerro Juanaqueña pursue, and what were the relative return rates of these strategies? One possibility is that the primary maize-farming strategy was focused on intermediate-cost, high-return floodplain farming, with little investment in higher cost *ak chin* farming and other strategies.

Maize return rates are also included in Figure 6.7 (Barlow 1997, 2002). Casual plant and harvest strategies have the highest return rates. Maize farming that requires minimum to intermediate field investment such as floodplain farming is the next highest. Third is typical maize farming. This was the most common in the Southwest and requires a significant level of field preparation, including water control devices. Fourth, intensive maize farming, which may have been rare in the prehistoric Southwest, has the lowest return rate. Note that plant and harvest maize farming has greater return rates than most non-domesticated lifeforms, except riparian taxa. The return rate of minimal field

investment farming (that is, slash and burn or floodplain farming) is similar to that of shrubs and nut resources, while the return rate of typical maize farming is similar to that of forbs and succulents. Only grasses fall below maize farming in return rates.

If intermediate-cost, high-return farming was the principal strategy we would expect future research to show that subsequent occupations indicate a pattern of switching back and forth between emphasis on hunting and gathering and high-return, low-investment farming. Alternating strategies would be affected by the availability of other wild resources with similar returns, particularly shrub and nut resources, as well as mammals. The role of farming in the economy would not be expected to increase appreciably as long as this strategy was being pursued; succulents and forbs would play an increasing role as the return rates of farming declined. Other contemporaneous sites should represent a range of foraging activities, and farming would be limited to floodplain and plant and harvest strategies.

The alternative is that Native Americans at Cerro Juanaqueña were engaged in typical farming strategies. If this is the case, further research should show a range in kinds of farming settlements, technologies, and locations being utilized. These may include *ak chin* farming, dry farming, and the use of water control devices, including irrigation. Increasing population density may have restricted access to shrubs, forbs, and succulents and encouraged typical maize farming. Because the return rates of typical maize farming are roughly similar to those of forbs and succulents, these lifeforms would be extensively utilized if typical maize farming was the strategy of the day. In fact virtually all of the charred seeds found in our botanical samples are forbs, which is more consistent with a typical farming strategy. The defensive character of Cerro Juanaqueña is suggestive of population packing as well.

In contrast to the Río Casas Grandes region, why did the Native Americans living in the Southern Jornada region not invest more in farming during the Late Archaic period? Although only located a few days' walk away, these populations elected to pursue a dominantly mobile, hunting and gathering system for another two millennia before adopting a mixed farming strategy at ca. AD 1000. Our preliminary vegetation comparison suggests that the simple frequency of wild edible species between the two regions is similar.

Unfortunately, the density of forbs and succulents on the landscape is difficult to know. It is almost a certainty, however, that shrub density was higher in the Southern Jornada region than in the Río Casas Grandes region. This is significant, because shrubs generally offer higher return rates than forbs, succulents, and grasses. Succulents probably existed at higher density in the Jornada region as well.

The farming potential in the Southern Jornada region was less favorable than in the Río Casas Grandes region. In the Southern Jornada region two-thirds of the mean annual rainfall of 23 cm falls between July and October, and droughts are common. Although the frost-free season is long, the limited fall, winter, and spring moisture inhibits plant growth until the July onset of the variable summer rains. A histogram of July–October rainfall at Las Cruces from 1959 to 1996 indicates that growing-season rainfall approximates a normal distribution about a mean of 14.9 cm (std. dev. = 5.4 cm, $n = 38$). This suggests that in about 50% of years the growing season rainfall will be well below the minimal 15 cm of direct moisture that needs to fall on maize fields in the absence of irrigation or water control (Shaw 1988) to produce a scant crop. Even assuming an increase in precipitation during the Late Archaic period, adequate moisture for predictable rain-fed farming is unlikely. In the absence of sufficient precipitation to support dry farming, agricultural fields must be located to take advantage of runoff or other moisture sources.

Based on the distribution of late prehistoric settlements (ca. AD 1100–1400) in the Southern Jornada region, the toes of the alluvial fans in the Hueco Bolson and Tularosa Valley and the Río Grande were the favored agricultural locations. Runoff from the mountain slopes and alluvial fans spreads and effectively enhances soil moisture. The Río Grande Valley offered higher soil moisture, with receding spring and early summer floodwaters and a high water table (Bradley 1983). The Río Grande, however, frequently experienced devastating spring floods, summer droughts, and periods of no flow (Ackerly 1995; Bradley 1983; Mauldin 1997). Prior to the 1915–1916 construction of Elephant Butte dam, historic farmers regularly had to rebuild irrigation systems as a result of dramatic floods (Ackerly 1994, 1995). Raymond Mauldin (1995, 1997) examined tree-ring and historic rainfall data for AD 1600–1900 and concluded that one-third of the years the Río Grande would experience disastrous floods or droughts. While farming in the Río Grande Valley may have been productive in some years, the risk was that at least one-third of the time crops would not produce adequately, if at all. In order to offset this risk prehistoric farmers perhaps planted in multiple locations, a strategy that would increase security but decrease return rates, due to the greater work involved (Hard and Merrill 1990; Huckell et al. 2002).

The archaeological record of the Southern Jornada region suggests that high levels of mobility were a key component of the adaptation and that maize played a minor economic role until ca. AD 1000–1100 (e.g., Hard et al. 1996; O'Laughlin 1980; Whalen 1994). The high return rates of shrubs should have made them a key resource, because they have higher rates than succulents, forbs, and typical farming strategies. There is some evidence that mesquite

was a significant prehistoric resource, as it was a common taxon in the Late Archaic deposits at Fresnal Shelter (Bohrer 1981). It is not commonly recovered from flotation samples in the region, however, perhaps due to preservation factors. Low-investment farming using a plant and harvest strategy may have been effective on a small scale. Risk-reduction strategies including intraband sharing, regional mobility, and storage were likely to have been utilized in the Southern Jornada region as well.

The late integration of significant levels of farming into the Southern Jornada economy may be related to both the high density of shrubs, succulents, and forbs and the absence of potential farming habitats that produced low-cost, high-yield maize, as found in the Río Casas Grandes. In fact, it is likely that the return rates on typical maize farming in the Southern Jornada area were lower than in many other places in the Southwest. Under these conditions, only a plant and harvest maize strategy was energetically practical. Thus farming was not a significant element in the economy for a full two millennia after the Río Casas Grandes was being farmed.

The Río Casas Grandes floodplain offered greater productivity and lower risk than the Río Grande Valley. This floodplain offered a local environment in which intermediate-investment farming may have yielded higher returns than many grasses, forbs, and succulents did. Only shrubs yield return rates on a par with intermediate-investment farming (Figure 6.7). Shrubs, although certainly not scarce in the Río Casas Grandes, would have been less dense across the landscape than in the Jornada region. The agricultural potential of the valley was particularly high, because it experienced a climatic regime of high moisture yet an absence of high-magnitude floods, and the water table was high. In addition the river originates at higher elevations where rainfall is significantly greater. A range of farming strategies including rain-fed farming, water-table farming, *ak chin* farming, and perhaps flood-recession farming would be possible. This diversity of potential farming strategies should reduce risk. High-return, high-yield maize farming conditions, combined with the use of available wild resources, provided a stable economic base that supported the aggregated semisedentary population of Cerro Juanaqueña for perhaps two centuries.

The presence of such a productive floodplain in an arid grassland may also have been an important consideration. This landscape did not offer the density of higher-return shrubs found in the vicinity of the Río Grande. The diet-breadth model suggests that, if shrub resources were sufficiently dense, additional investment in low-investment maize farming would not have been necessary for a given population level. However, grasses and forbs dominated the landscape in the vicinity of Cerro Juanaqueña. Grasses have return rates

lower than both floodplain farming and typical farming. Forb return rates are about equivalent to those of typical farming. In other words, farming in the Río Casas Grandes Valley probably offered higher return rates than the landscape's grasses and forbs. In addition the defensive character of the *cerros de trincheras* sites is indicative of population packing. Higher population density may have restricted access to higher-return resources, and perhaps the raiding environment made foraging risky.

Conclusions

In conclusion, we suggest that the high-density, high-return shrubs as well as the succulent and forb resources in the Southern Jornada region were juxtaposed with farming conditions that both were risky and yielded low-return maize harvests. As a result the optimal dietary mix emphasized nondomesticated resources and frequent mobility. Improvement in farming conditions due to increased rainfall during the late Holocene did not produce the low-cost maize yields needed to warrant abandonment of high levels of reliance on shrubs, forbs, and succulents that continued for another two millennia. The relatively high return of shrub resources and the mobility required to exploit them were favored relative to the lower return and higher risk of farming. Minimal investment in plant and harvest farming that was compatible with residential mobility allowed pursuit of the shrub, forb, and succulent resources that dominated the diet until ca. AD 1000.

In contrast, along the Río Casas Grandes we can point to the superior farming conditions that would have offered return rates on a par with typical farming strategies or perhaps as great as those of slash and burn or floodplain farming return rates. A diversity of potential farming strategies served to reduce risk. Under these conditions, increased investment in farming relative to hunting and gathering was an attractive option for two reasons. First, higher densities of lower-return grasses and forbs rather than shrubs characterized the landscape. Recall that grasses have return rates lower than those of most farming strategies and that forbs have return rates similar to those of typical farming strategies. Therefore farming in the Río Casas Grandes tended to have higher return rates than many of the wild plant resources that dominated the landscape. In addition the defensive nature of Cerro Juanaqueña and other *cerros de trincheras* sites suggests that the population was relatively high relative to resources. High populations may have limited access to wild plants due to population density and perhaps because freely foraging on the landscape was dangerous.

Finally, an optimal foraging framework suggests that whether the population is local or recently arrived it should make a similar sequence of decisions

based on alternatives available. Neither pushes nor pulls to farming have a necessary priority; they are weighed within the contexts of available alternatives at the local level. The calculation to farm or not to farm and to what degree is related to the relative costs and benefits of available options. The long-term course of cultural evolution is a product of these options and their selection. Although this framework is somewhat different from previous approaches to early farming in the Southwest and derives from the work of Barlow (1997, 2002), it does lend support to the floodplain priority models advocated by others (Huckell 1995; Mabry 1998; Mabry et al. 1997; Smith 1998) and predicted by Matson (1991). This work, however, places floodplain farming in the context of optimal foraging theory and therefore considers the options offered by nondomesticated along with domesticated resources in particular contexts.

ACKNOWLEDGMENTS

The National Science Foundation (BCS-0219185, SBR-9809839, SBR-9708610) and the National Geographic Society Committee for Research and Exploration (Grant #6749-00) provided funding for this work. The Consejo de Arqueología of the Instituto Nacional de Antropología e Historia (INAH) in Mexico City and the Centro INAH Chihuahua in Cd. Chihuahua provided permits, encouragement, and support of the project. The staff at the Center for Archaeological Research at the University of Texas at San Antonio provided equipment as well as administrative and laboratory support. Our wonderful field team made the difficult, hot fieldwork from 1997 to 2000 most enjoyable. We greatly appreciate the support of all these agencies and individuals and are especially grateful to Brad Vierra for the opportunity to participate in an outstanding symposium and for his efforts to produce this volume.

REFERENCES CITED

Ackerly, N. W. (editor)

- 1994 Historic and Modern Irrigation Systems. In *El Valle Bajo: The Culture History of the Lower Rio Grande Valley of El Paso*, vol. 1, *Culture and Environment in the Lower Valley*, edited by J. Peterson and D. O. Brown, pp. 130–141. Archeological Research, Inc., El Paso, and Hicks and Co., Austin, Tex.
- 1995 Important Variables for Prehistoric Irrigation Studies. In *Soil, Water, Biology, and Belief in Prehistoric and Traditional Southwestern Agriculture*, edited by H. W. Toll, pp. 279–288. Special Publication No. 2. New Mexico Archaeological Council, Albuquerque.

Adams, J.

- 1999 Refocusing the Role of Food-Grinding Tools as Correlates for Subsistence Strategies in the U.S. Southwest. *American Antiquity* 64: 475–498.

Adams, K. R.

- 1998 Plant Remains Recovered from Juanaqueña, a Late Archaic (3000 BP) Trincheras Site in Northern Chihuahua. Unpublished manuscript on file at the Center for Archaeological Research, San Antonio.
- 1999a Plant Remains Recovered in 1998 from Cerro Juanaqueña, Cerro Vidal, and Cerros los Torres, Trincheras Sites in Northern Chihuahua. Unpublished manuscript on file at the Center for Archaeological Research, San Antonio.
- 1999b Plant Remains Recovered in 1999 from Cerro Juanaqueña, Cerro Vidal, and Cerros los Torres, Trincheras Sites in Northern Chihuahua. Unpublished manuscript on file at the Center for Archaeological Research, San Antonio.

Arbolino, R. D.

- 2001 Agricultural Strategies and Labor Organization: An Ethnohistoric Approach to the Study of Prehistoric Farming Systems in the Taos Area of Northern New Mexico. Ph.D. dissertation, Department of Southern Methodist University, Dallas.

Barlow, K. R.

- 1997 Foragers That Farm: A Behavioral Ecology Approach to the Economics of Corn Farming for the Fremont Case. Ph.D. dissertation, Department of Anthropology, University of Utah.
- 2002 Predicting Maize Agriculture among the Fremont: An Economic Comparison of Farming and Foraging in the American Southwest. *American Antiquity* 67: 65–88.

Berry, M. S.

- 1982 *Time, Space, and Transition in Anasazi Prehistory*. University of Utah Press, Salt Lake City.

Bohrer, Vorsila L.

- 1981 Former Dietary Patterns of People as Determined from Archaic-Age Plant Remains from Fresnal Shelter, South-Central New Mexico. *Artifact* 19: 41–50.

Bradley, R. J. E.

- 1983 La Cabrana: A Study of Fourteenth-Century Resource Utilization in Southern New Mexico. Master's thesis, Department of Anthropology, University of Texas at El Paso.

Brand, D. D.

- 1937 *The Natural Landscape of Northwestern Chihuahua*. University of New Mexico Press, Albuquerque.

Bronk Ramsey, R. C.

- 1999 OxCal Program v3.3. Radiocarbon Accelerator Unit, University of Oxford. <http://www.rlaha.ox.ac.uk/oxcal/oxcal.htm>.

Brown, David E.

- 1982a Appendix II: Scientific and Equivalent Common Names of Plants and Animals Used as Examples in the Text, Arranged by Biomes. In *Biotic Communities of the American Southwest—United States and Mexico, Desert Plants*, vol. 4, nos. 1–4, edited by D. E. Brown, pp. 316–341. University of Arizona Press, Tucson.
- 1982b Chihuahuan Desertscrub. In *Biotic Communities of the American Southwest—United States and Mexico, Desert Plants*, vol. 4, nos. 1–4, edited by D. E. Brown, pp. 169–179. University of Arizona Press, Tucson.
- 1982c Semidesert Grassland. In *Biotic Communities of the American Southwest—United States and Mexico, Desert Plants*, vol. 4, nos. 1–4, edited by D. E. Brown, pp. 123–131. University of Arizona Press, Tucson.

Brown, D. E., and C. H. Lowe

- 1983 *Biotic Communities of the Southwest* (map). General Technical Report RM-78, Rocky Mountain Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture, Fort Collins.

Buck, B. J., and H. C. Monger

- 1999 Stable Isotopes and Soil-Geomorphology as Indicators of Holocene Climate Change, Northern Chihuahuan Desert. *Journal of Arid Environments* 43:357–373.

Burgess, T. L.

- 1995 Desert Grassland, Mixed Shrub Savanna, Shrub Steppe, or Semi-desert Scrub? In *The Desert Grassland*, edited by M. P. McClaran and T. R. Van Devender, pp. 31–67. University of Arizona Press, Tucson.

Burns, B. T.

- 1983 Simulated Anasazi Storage Behavior Using Crop Yields Reconstructed from Tree Rings: AD 652–1968. Ph.D. dissertation, Department of Anthropology, University of Arizona, Tucson.

Castiglia, P. J.

- 2002 Late Quaternary Climate History of the Pluvial Lake Palomas Sys-

tem, Northern Chihuahua, Mexico. Master's thesis, University of New Mexico, Albuquerque.

Dering, P.

- 1999 Earth-Oven Plant Processing in Archaic Period Economies: An Example from a Semi-Arid Savannah in South-Central North America. *American Antiquity* 64:659–674.

Dick-Peddie, W. A.

- 1993 *New Mexico Vegetation: Past, Present, and Future*. University of New Mexico Press, Albuquerque.

Doelle, W. H.

- 1976 *Desert Resources and Hohokam Subsistence: The Conoco Florence Project*. Archaeological Series No. 103. Cultural Resources Management Section, Arizona State Museum, University of Arizona, Tucson.

Doolittle, W. E.

- 2000 *Cultivated Landscapes of Native North America*. Oxford University Press, New York.

Ely, L. L.

- 1997 Response of Extreme Floods in the Southwestern United States to Climatic Variations in the Late Holocene. *Geomorphology* 19:175–202.

Fleischauer, H. L., Jr., and W. J. Stone

- 1982 *Quaternary Geology of Lake Animas, Hidalgo County, New Mexico*. Circular 174. New Mexico Bureau of Mines and Mineral Resources, Socorro.

Fritz, G.

- 1994 Are the First American Farmers Getting Younger? *Current Anthropology* 35:305–309.

Fritz, G., K. Adams, R. J. Hard, and J. R. Roney

- 1999 Evidence for Cultivation of *Amaranthus* sp. (Amaranthaceae) 3,000 Years Ago at Cerro Juanaqueña, Chihuahua. Paper presented at the 22nd Annual Conference of the Society of Ethnobiology, Oaxaca, Mexico.

Glassow, Michael A.

- 1980 *Prehistoric Agricultural Development in the Northern Southwest: A Study in Changing Patterns of Land Use*. Ballena Press, Socorro, N.Mex.

Hanselka, J. K.

- 2000 Late Archaic Plant Use and Early Agriculture in Northwestern Chihuahua, Mexico: Insights from Cerros de Trincheras Sites.

Master's thesis, Department of Anthropology, University of Texas at San Antonio.

Hard, R. J.

- 1990 Agricultural Dependence in the Mountain Mogollon. In *Perspectives on Southwestern Prehistory*, edited by P. E. Minnis and C. L. Redman, pp. 135–149. Westview Press, Boulder, Colo.
- 1997 A Comparative Analysis of Agricultural Dependence in the Northern and Southern Jornada Mogollon Regions. In *Proceedings of the Ninth Jornada-Mogollon Conference*, edited by R. Mauldin, J. Leach, and S. Ruth, pp. 93–98. Publications in Archaeology No. 12. Centro de Investigaciones Arqueológicas, El Paso, Tex.

Hard, R. J., R. P. Mauldin, and G. R. Raymond

- 1996 Mano Size, Stable Carbon Isotope Ratios, and Macrobotanical Remains as Multiple Lines of Evidence of Maize Dependence in the American Southwest. *Journal of Archaeological Method and Theory* 3:253–318.

Hard, R. J., and W. L. Merrill

- 1990 Mobile Agriculturalists and the Emergence of Sedentism: Perspectives from Northern Mexico. *American Anthropologist* 94:601–620.

Hard, R. J., and J. R. Roney

- 1998a A Massive Terraced Village Complex in Chihuahua, Mexico, 3000 Years Before Present. *Science* 279:1661–1664.
- 1998b Una investigación arqueológica de los sitios Cerros con Trincheras del Arcáico Tardío en Chihuahua, México: Las investigaciones de campo de 1997. Informe al Consejo de Arqueología, Instituto Nacional de Antropología e Historia. Center for Archaeological Research, University of Texas at San Antonio.
- 1999 An Archaeological Investigation of Late Archaic Cerros de Trincheras Sites in Chihuahua, Mexico: Results of the 1998 Investigations. Special Report No. 25. Center for Archaeological Research, University of Texas at San Antonio.
- 2004 Late Archaic Period Hilltop Settlements in Northwestern Chihuahua, Mexico. In *Identity, Feasting, and the Archaeology of the Greater Southwest*, edited by B. J. Mills, pp. 276–294. University Press of Colorado, Boulder.

Hard, R. J., J. E. Zapata, B. K. Moses, and J. R. Roney

- 1999 Terrace Construction in Northern Chihuahua, Mexico: 1150 BC and Modern Experiments. *Journal of Field Archaeology* 26:129–146.

Haury, E. W.

- 1962 The Greater American Southwest. In *Courses toward Urban Life*, edited by R. Braidwood and G. Willey, pp. 106–131. Viking Fund Publications in Anthropology 32. Wenner-Gren Foundation for Anthropological Research, New York.

Heerwagen, A.

- 1956 Mixed Prairie in New Mexico. In *Grasslands of the Great Plains*, edited by J. E. Waver and F. W. Albertson, pp. 284–300. Johnson Publishing, Lincoln, Neb.

Hill, J.

- 2001 Proto-Uto-Aztec: A Community of Cultivators in Central Mexico. *American Anthropologist* 103:913–934.

Huckell, B. B.

- 1995 *Of Marshes and Maize: Preceramic Agricultural Settlements in the Cienega Valley, Southeastern Arizona*. Anthropological Papers of the University of Arizona No. 59. University of Arizona Press, Tucson.
- 1997 The Archaic Prehistory of the North American Southwest. *Journal of World Prehistory* 10:305–374.

Huckell, B. B., L. W. Huckell, and K. B. Benedict

- 2002 Maize Agriculture and the Rise of Mixed Farming-Foraging Economies in Southeastern Arizona during the Second Millennium. In *Traditions, Transitions, and Technologies: Themes in Southwestern Archaeology, Proceedings of the 2000 Southwest Symposium*, edited by S. Schlanger, pp. 137–159. University Press of Colorado, Boulder.

Huckell, B. B., L. W. Huckell, and S. K. Fish

- 1995 *Investigations at Milagro, a Late Preceramic Site in the Eastern Tucson Basin*. Technical Report 94(5). Center for Desert Archaeology, Tucson.

Johnson, A. E.

- 1960 The Trincheras Culture of Northern Sonora. *American Antiquity* 29:174–186.

Kaplan, H., and K. Hill

- 1985 Food Sharing among Ache Foragers: Tests of Explanatory Hypotheses. *Current Anthropology* 26:223–245.
- 1992 The Evolutionary Ecology of Food Acquisition. In *Evolutionary Ecology and Human Behavior*, edited by E. A. Smith and B. Winterhalder, pp. 167–202. Aldine de Gruyter, New York.

Krider, R. Reed

- 1998 Paleoclimatic Significance of Late Quaternary Lacustrine and Alluvial Stratigraphy, Animas Valley, New Mexico. *Quaternary Research* 50:283–289.

Legler, R. P.

- 1970 Habitat Preference of the Desert Cottontail with Additional Notes on the Black-tailed Jackrabbit. Master's thesis, New Mexico State University, Las Cruces.

Lehmer, D. J.

- 1948 *The Jornada Branch of the Mogollon*. University of Arizona Bulletin, Social Science Bulletin 17, vol. 19, no. 2.

Mabry, J. B.

- 2002 The Role of Irrigation in the Transition to Agriculture and Sedentism in the Southwest. In *Traditions, Transitions, and Technologies: Themes in Southwestern Archaeology, Proceedings of the 2000 Southwest Symposium*, edited by S. Schlanger, pp. 178–199. University Press of Colorado, Boulder.
- 2003 Diversity in Early Southwestern Farming Systems and Optimization Models of Transitions to Agriculture. In *Subsistence and Resource Use Strategies in Early Agricultural Communities in Southern Arizona*, edited by M. W. Diehl. Anthropological Paper No. 34. Center for Desert Archaeology, Tucson. (Draft.)

Mabry, J. B. (editor)

- 1998 *Archaeological Investigations of Early Village Sites in the Middle Santa Cruz Valley. Part II: Analysis and Synthesis*. Anthropological Papers No. 19. Center for Desert Archaeology, Tucson.

Mabry, J. B., D. L. Swartz, H. Wöcherl, J. J. Clark, G. H. Archer, and M. W. Lindeman

- 1997 *Archaeological Investigations of Early Village Sites in the Middle Santa Cruz Valley: Description of the Santa Cruz Bend, Square Hearth, Stone Pipe, and Canal Sites*. Anthropological Papers No. 18. Center for Desert Archaeology, Tucson.

MacNeish, Richard S. (editor)

- 1993 *Preliminary Investigations of the Archaic in the Region of Las Cruces, New Mexico*. Historic and Natural Resources Report No. 9. Cultural Resources Management Branch, Directorate of Environment, Fort Bliss, Tex.

Martin, P. S., J. B. Rinaldo, E. Bluhm, H. C. Cutler, and R. Grange, Jr.

- 1952 *Mogollon Cultural Continuity and Change: The Stratigraphic*

Analysis of Tularosa and Cordova Caves. Fieldiana, vol. 40. Field Museum of Natural History, Chicago.

Matson, R. G.

- 1991 *The Origins of Southwestern Agriculture*. University of Arizona Press, Tucson.

Mauldin, R. P.

- 1993 The Relationship between Ground Stone and Agricultural Intensification in Western New Mexico. *Kiva* 58:317–330.
- 1995 Groping for the Past: Investigating Archaeological Patterns across Space and Time in the Southern Southwestern United States. Ph.D. dissertation, Department of Anthropology, University of New Mexico, Albuquerque.
- 1997 Patterns of Climate and Production in the Past and Present Jornada. In *Proceedings of the Ninth Jornada-Mogollon Conference*, edited by R. P. Mauldin, J. D. Leach, and S. Ruth, pp. 11–28. Publications in Archaeology No. 12. Centro de Investigaciones Arqueológicas, El Paso, Tex.

McGuire, R. H., and J. McNiff

- 1990 Cerros de Trincheras and the Cultural Landscape of Northern Sonora Mexico. Paper presented at the 55th Annual Meeting of the Society for American Archaeology, Las Vegas.

McGuire, R. H., and M. E. Villalpando

- 1993 Proyecto reconocimiento arqueológico en el Valle del Altar. Report to Instituto Nacional de Antropología e Historia, Mexico City.

McGuire, R. H., M. E. Villalpando C., V. D. Vargas, and E. Gallaga M.

- 1999 Cerro de Trincheras and the Casas Grandes World. In *The Casas Grandes World*, edited by C. F. Schaafsma and C. L. Riley, pp. 134–146. University of Utah Press, Salt Lake City.

Mehring, P. J., P. S. Martin, and C. V. Haynes, Jr.

- 1967 Murray Springs, a Mid-Postglacial Pollen Record from Southern Arizona. *American Journal of Science* 265:786–797.

Metcalfe, S. E., A. Bimpson, A. J. Courtice, S. L. O'Hara, and D. M. Taylor

- 1997 Climate Change at the Monsoon/Westerly Boundary in Northern Mexico. *Journal of Paleolimnology* 17:155–171.

Minnis, P. E.

- 1992 Earliest Plant Cultivation in the Desert Borderlands of North America. In *The Origins of Agriculture: An International Perspective*, edited by C. W. Cowan and P. J. Watson, pp. 121–142. Smithsonian Institution Press, Washington and London.

Moerman, D.

- 2001 Native American Ethnobotany Database: Foods, Drugs, Dyes, Fibers of Native North American Peoples. University of Michigan, Dearborn. <http://www.umd.umich.edu/cgi-bin/herb/>.

Nordt, Lee

- 2003 Late Quaternary Fluvial Landscape Evolution in Desert Grasslands of Northern Chihuahua, Mexico. *Geological Society of American Bulletin* 115:596–606.

O'Donovan, M.

- 2002 *New Perspectives of Site Function and Scale of Cerro de Trincheras, Sonora, Mexico: The 1991 Surface Survey*. Arizona State Museum Archaeological Series No. 195. University of Arizona Press, Tucson.

O'Laughlin, T. C.

- 1980 *The Keystone Dam Site and Other Archaic and Formative Sites in Northwest El Paso, Texas*. Publications in Anthropology No. 8. University of Texas at El Paso, El Paso.

Ortega-Ramírez, J.

- 1995a Correlación estratigráfica de los depósitos cuaternarios de la Laguna de Babícara, Chihuahua, México. *Geofísica Internacional* 34:117–129.
- 1995b Los paleoambientes holocénicos de la Laguna de Babícara, Chihuahua, México. *Geofísica Internacional* 34:107–116.

Ortega-Ramírez, J. R., A. Valiente-Banuet, J. Urrutia-Fucugauchi, C. A. Martera-Gutiérrez, and G. Alvarado-Valdez

- 1998 Paleoclimatic Changes during the Late Pleistocene-Holocene in Laguna Babícara, near the Chihuahuan Desert, México. *Canadian Journal of Earth Science* 35:1168–1179.

Polyak, V. J., and Y. Asmerom

- 2001 Late Holocene Climate and Cultural Changes in the Southwestern United States. *Science* 294:148–151.

Rhode, D.

- 1995 Estimating Agricultural Carrying Capacity in the Zuni Region, West-Central New Mexico: A Water Allocation Model. In *Soil, Water, Biology, and Belief in Prehistoric and Traditional Southwestern Agriculture*, edited by H. W. Toll, pp. 85–101. Special Publication 2. New Mexico Archaeological Council, Albuquerque.

Roney, J. R., and R. J. Hard

- 2000 *Una investigación arqueológica de los Sitios Cerros con Trincheras del Arcáico Tardío en Chihuahua, México: Las investigaciones de*

campo de 1999. Special Report No. 26-S. Center for Archaeological Research, University of Texas at San Antonio.

- 2002 Early Agriculture in Northwestern Chihuahua. In *Tradition: Transitions, and Technologies: Themes in Southwestern Archaeology, Proceedings of the 2000 Southwest Symposium*, edited by S. Schlanger, pp. 160–177. University Press of Colorado, Boulder.
- 2004 A Review of Cerros de Trincheras in Northwestern Chihuahua. In *Surveying the Archaeology of Northwest Mexico*, edited by G. F. Newell and E. Gallaga, pp. 127–147. University of Utah Press, Salt Lake City.

Roth, B. J., and B. B. Huckell

- 1992 Cortaro Points and the Archaic of Southern Arizona. *Kiva* 57:353–370.

Sauer, C., and D. Brand

- 1931 Prehistoric Settlements of Sonora with Special Reference to Cerros de Trincheras. In *University of California Publications in Geography* 5:67–148. University of California Press, Berkeley.

Schmidt, K., and J. Nisengard

- 1999 1998 Investigations: A Report on the Faunal Remains for Cerro Juanaqueña, Cerro Los Torres, and Cerro Vidal, Chihuahua, Mexico. Unpublished manuscript on file at the Center for Archaeological Research, San Antonio.
- 2000 Recent Faunal Analysis from Cerros de Trincheras Sites in Northwestern Chihuahua. Paper presented at the 65th Annual Meeting of the Society of American Archaeology, Philadelphia.

Shaw, R. H.

- 1988 Climate Requirement. In *Corn and Corn Improvement*, edited by G. F. Sprague and J. W. Dudley, pp. 609–638. 3rd ed. Agronomy No. 18. American Society of Agronomy, Madison, Wis.

Shuster, R. A., and R. A. Bye, Jr.

- 1984 Part II: Preliminary Results from the Dolores Archaeological Program Gardens. In *Dolores Archaeological Program: Synthetic Report 1978–1981*, pp. 94–99. U.S. Department of the Interior, Bureau of Reclamation, Engineering and Research Center, Denver.

Simms, S. R.

- 1986 Acquisition Cost and Nutritional Data on Great Basin Resources. *Journal of California and Great Basin Anthropology* 8 (2):117–126.
- 1987 *Behavioral Ecology and Hunter-Gatherer Foraging: An Example from the Great Basin*. BAR International Series 381. British Archaeological Reports, Oxford, England.

- Smiley, F.**
1994 The Agricultural Transition in the Northern Southwest: Patterns in the Current Chronometric Data. *Kiva* 60:165–189.
- Smith, B. D.**
1998 *The Emergence of Agriculture*. 2nd ed. Scientific American Library, New York.
- Smith, G. D., and M. McFaul**
1997 Paleoenvironmental and Geoarchaeologic Implications of Late Quaternary Sediments and Paleosols: North-Central to Southwestern San Juan Basin, New Mexico. *Geomorphology* 21: 107–138.
- Stacy, V. K. P.**
1974 Cerros de Trincheras in the Arizona Papaveria. Ph.D. dissertation, Department of Anthropology, University of Arizona, Tucson.
- Turner, E. S., and T. R. Hester**
1995 *A Field Guide to Stone Artifacts of Texas Indians*. 2nd ed. Gulf Publishing, Houston.
- Turpin, S. A.**
1991 Time Out of Mind: The Radiocarbon Chronology of the Lower Pecos River Region. In *Papers on Lower Pecos Prehistory*, vol. 8, edited by S. A. Turpin, pp. 1–49. Studies in Archeology 8. Texas Archeological Research Laboratory, University of Texas at Austin.
- Urrutia-Fucugauchi, J., J. Ortega-Ramírez, and R. Cruz-Gatica**
1997 Rock-Magnetic Study of Late Pleistocene–Holocene Sediments from the Babicora Lacustrine Basin, Chihuahua, Northern Mexico. *Geofísica Internacional* 36:77–86.
- Van Auken, O. W.**
2000 Shrub Invasions of North American Semiarid Grasslands. *Annual Review of Ecological Systems* 31:197–215.
- Van Devender, T. R.**
1990 Late Quaternary Vegetation and Climate of the Chihuahuan Desert, United States and Mexico. In *Packrat Middens: The Last 40,000 Years of Biotic Change*, edited by J. L. Betancourt, T. R. Van Devender, and P. S. Martin, pp. 104–133. University of Arizona Press, Tucson.
1995 Desert Grassland History: Changing Climates, Evolution, Biogeography, and Community Dynamics. In *The Desert Grassland*, edited by M. P. McClaran and T. R. Van Devender, pp. 68–99. University of Arizona Press, Tucson.
- Van Devender, T. R., and R. D. Worthington**
1977 The Herpetofauna of Howell's Ridge Cave and the Paleoecology of the Northwestern Chihuahuan Desert. In *Transactions of the Symposium on the Biological Resources of the Chihuahuan Desert Region: United States and Mexico*, edited by R. H. Wauer and D. H. Riskind, pp. 85–106. No. 3, National Park Service Transactions and Proceedings Series. U.S. Department of the Interior, Washington, D.C.
- Ward, G. K., and S. R. Wilson**
1978 Procedures for Comparing and Combining Radiocarbon Age Determinations: A Critique. *Archaeometry* 20:19–31.
- Waters, M. R.**
1989 Late Quaternary Lacustrine History and Paleoclimatic Significance of Pluvial Lake Cochise, Southeastern Arizona. *Quaternary Research* 32:1–11.
- Waters, M. R., and C. V. Haynes**
2001 Late Quaternary Arroyo Formation and Climate Change in the American Southwest. *Geology* 29:399–402.
- Whalen, M. E.**
1994 Moving Out of the Archaic on the Edge of the Southwest. *American Antiquity* 59:606–621.
- Wilcox, D. R.**
1979 Warfare Implications of Dry-Laid Masonry Walls on Tumamoc Hill. *Kiva* 45:15–38.
- Wilkens, D. E., and D. R. Currey**
1999 Radiocarbon Chronology and $\delta^{13}\text{C}$ Analysis of Mid- to Late-Holocene Aeolian Environments, Guadalupe Mountains National Park, Texas, USA. *Holocene* 9:363–371.
- Wills, W. H.**
1988 Early Agriculture and Sedentism in the American Southwest: Evidence and Interpretations. *Journal of World Prehistory* 2: 445–488.
- Winterhalder, B.**
1986 Diet Choice, Risk, and Food Sharing in a Stochastic Environment. *Journal of Anthropological Archaeology* 5:369–392.
- Winterhalder, B., and C. Goland**
1997 An Evolutionary Ecology Perspective in Diet Choice, Risk, and

Plant Domestication. In *People, Plants, and Landscapes: Studies in Paleobotany*, edited by K. J. Gremillion, pp. 123–259. University of Alabama Press, Tuscaloosa.

York, J. C., and W. A. Dick-Peddie

- 1969 Vegetation Changes in Southern New Mexico during the Past Hundred Years. In *Arid Lands in Perspective*, edited by W. G. McGinnies and B. J. Goldman, pp. 157–199. University of Arizona Press, Tucson.

Zavala, B. G.

- 1998 Building Trincheras: An Analysis of Architectural Features at Cerro de Trincheras. Master's thesis, Department of Anthropology, State University of New York at Binghamton.

Zeanah, D. W., J. A. Carter, D. P. Dugas, R. G. Elston, and J. E. Hammett

- 1995 *An Optimal Foraging Model of Hunter-Gatherer Land Use in the Carson Desert*. Intermountain Research, Silver City, Nev.

Late Archaic Stone Tool Technology across the Borderlands

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Introduction

The Late Archaic (ca. 3000–1500 BP) along the U.S./Mexican Borderlands is characterized by a diverse set of agricultural and foraging economic strategies. Current research indicates that areas of the Sonoran and Chihuahuan Deserts contain evidence for an early dependence on agriculture with sedentism, vs. foragers who repeatedly reoccupied specific site locations in the Tamaulipas region of South Texas. This varied archaeological record provides an excellent opportunity to evaluate current arguments concerned with explaining technological variation. This chapter presents the preliminary results of the analyses of chipped stone artifacts from the Late Archaic *trincheras* site of Cerro Juanaqueña, Chihuahua, Mexico, and contrasts this information with other sites along the Borderlands. It discusses the possible effects of subsistence, mobility, and raw material availability on Late Archaic stone tool technology.

Late Archaic Stone Tool Technology

Recent research on stone tool technology has emphasized residential mobility as a possible explanation for technological variation. This perspective often assumes that mobility limits the size and number of tools that a group can efficiently carry with it (Carr 1994; Ebert 1979; Kuhn 1994; Shott 1986). For example, William Parry and Robert Kelly (1987) suggest that bifaces are portable tools that can also act as cores, which is important for mobile groups with varying access to lithic materials, whereas a simple flake technology is sufficient for sedentary groups with access to locally available materials. Another important aspect of bifacial technologies is the ability to increase tool use-life through resharpening (Kelly 1988).

The effect of lithic material availability on stone tool technology is another possible explanation for technological variation. These arguments are often